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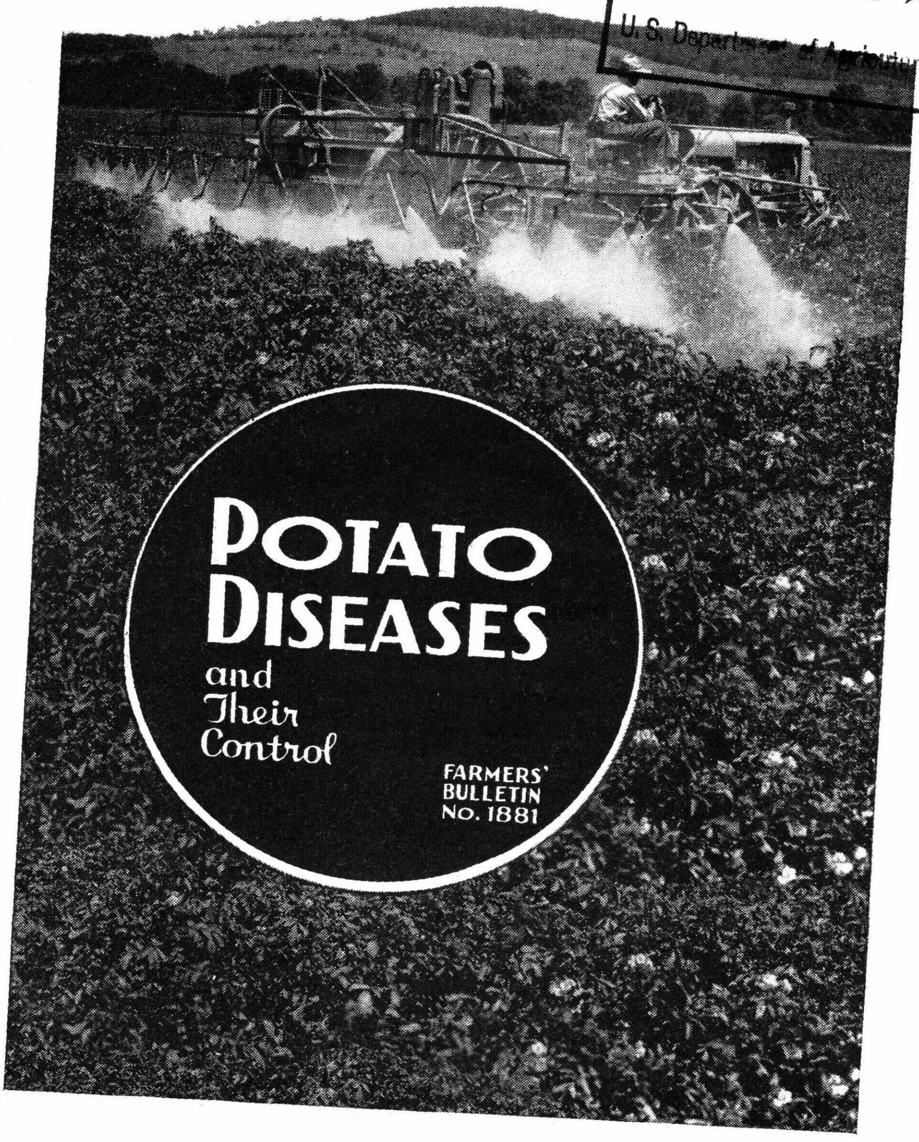

POTATO DISEASES and Their Control

FARMERS' BULLETIN No. 1881

POTATO diseases may be caused by bacteria, fungi, viruses, and physiological factors.

The occurrence and the seriousness of these diseases are to a large extent influenced by environmental conditions, such as humidity and temperature. On account of prevailing climatic conditions unfavorable to the development of some diseases, certain maladies of the potatoes never occur in some areas, whereas the same disease may be of major importance in other regions.

The certified seed-potato industry has to be located in areas where climatic conditions are favorable for the expression of virus diseases, in order that such diseases can be properly eliminated by roguing.

This bulletin describes the characteristics of the many potato diseases and discusses the various methods of control, such as seed treatment, spraying, dusting, and roguing.

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POTATO DISEASES AND THEIR CONTROL

By T. P. DYKSTRA, *pathologist, Division of Fruit and Vegetable Crops and Diseases, Bureau of Plant Industry*

Contents

INTRODUCTION

THE POTATO is subject to many diseases. These fall into four main groups, namely, those caused by bacteria, by fungi, by viruses, and by environmental conditions. Some of these diseases are very serious in certain parts of the country, but may be of practically no importance in other areas. Late blight, for instance, might cause crop failures in the North Atlantic States if the disease were not properly controlled, but it is of very minor importance in the Middle West or the Pacific Coast States. Brown rot, also known as bacterial wilt, is found only in the South and does not develop in the Northern States. There is restricted prevalence of some of the other diseases because development of disease to a large extent is influenced by environmental conditions such as temperature and humidity. It is fortunate that practically all of the diseases affecting the potato can be successfully controlled, but control has to be based upon prevention rather than cure. If a potato plant is attacked by an infectious disease it cannot be cured, but the spread of the disease

can be prevented by such measures as spraying, roguing, seed treatment, and crop rotation.

The growing of potatoes is an important and generally a profitable industry. In 1938 there were 3,008,000 acres in potatoes, producing 369,297,000 bushels, or an average of 122 bushels per acre. The crop in 1938 was valued to the grower at an average of $70 per acre, or $210,153,000 for the entire crop in the United States. The losses due to potato diseases in that year were estimated at one-sixth of the crop, with a valuation of $35,000,000.

The potato industry consists of two specialized branches, namely, the production of (1) seed potatoes and (2) table stocks. The seed-potato production areas are restricted to those localities where temperature and soil conditions are suitable for the growing of potatoes of excellent quality and free from disease. The successful seed-potato grower has to be familiar with the nature of potato diseases and their means of transmission in order to know how to prevent and eradicate these troubles. Many of these diseases are carried over in the tubers, which, when planted, will produce diseased plants. Most of the virus diseases show symptoms only in the foliage, and, although infection results in reduced yields, the tubers do not show any external or internal symptoms. These diseases have to be eliminated by roguing diseased plants in the field to remove infected plants and to prevent spread.

In every State where the growing of seed potatoes is carried on extensively, certification agencies, sponsored either by the State or by potato-growers' associations, have been established. These agencies inspect the fields two or three times during the growing season for the presence of disease and in many cases supplement this by a bin inspection for the presence of tuber diseases. If the fields registered for certification meet the requirements, the grower is furnished with tags that declare that his potatoes do not contain an excess of a designated low percentage of disease and are suitable for seed purposes.

The production of certified seed potatoes requires considerable care, but the grower's efforts are usually rewarded by the extra premium his crop commands as high grade seed.

The production of table stock is not so highly specialized. The grower plants certified seed and, if necessary, treats the tubers for the control of certain tuber-borne diseases, such as rhizoctonia canker, and sprays for the prevention of late blight, early blight, psyllid yellows, or flea beetle or leafhopper injury. Contrary to the practices of the potato-seed producer, he makes no effort to eliminate in the field plants infected with viruses, wilt, or other diseases that do not directly impair the eating qualities of potatoes.

In many potato-growing States the State agricultural experiment station has made a special study of potato-disease control under local conditions, and, therefore, it would be advisable for the interested grower to get in touch with the experiment station or with the local extension service specialist for guidance before deciding upon a program of control practices.

The purpose of this bulletin is to describe the characteristics of the different potato diseases and to give the control measures that have been found most practical and effective in eliminating or reducing the losses caused by them.

POTATO DISEASES

It is necessary to diagnose the symptoms of a disease accurately in order to know what control measures to adopt. This means that the entire plant, including the leaves, stems, roots, and tubers, may have to be examined for lesions or discolorations. In some cases it may be necessary to make microscopic examinations of affected tissues, or the causal organism, if a fungus or bacterium, may have to be isolated and grown on artificial media before accurate identification of the disease can be made. When the grower has difficulty in making a diagnosis, it is advisable to send the affected plants or tubers to the State agricultural experiment station for examination.

To aid the grower in identifying the diseases affecting his potato crop, a key has been prepared. After the grower has identified the disease he can turn to the page where it is described more fully and find the recommendations for its control.

KEY FOR IDENTIFYING POTATO DISEASES

Diseases Affecting Plant Tops.

A. Foliage yellow, or showing dead areas, accompanied or followed by rolling or wilting.

- (a) Lower part of stem inky black; leaves rolling. In advanced stages plant wilts. Seed piece completely rotted---- Blackleg (p. 6).
- (b) Leaves wilting; finally entire plant wilts. Vascular bundles in the stem, roots, and stolons turn brown. When vascular bundles of affected parts are cut, bacteria ooze from them as a milky white slimy mass--------------- Brown rot (bacterial wilt) (p. 8).
- (c) Leaves yellowish, but not always conspicuously. Dead areas often between veins as well as along margins; rolling at tips of leaves, followed by wilting. Vascular bundles normal in color-------------------- Ring rot (bacterial ring rot) (p. 10).
- (d) Leaves wilting or rolling and often yellowish. Stem firm without any external lesions. Inner tissue stained brown up to surface of ground-- Verticillium wilt or *Fusarium oxysporum* wilt (p. 23).
- (e) Symptoms somewhat similar to (d) above, but with internal flecking of stem, which may extend to upper leaflets. Usually stem-end rot or vascular discoloration of tuber in field. Bronzing and slight yellowing of upper leaflets is more characteristic than wilting and rolling------ *Fusarium eumartii* wilt (p. 23).
- (f) Young leaves fail to enlarge normally and the leaflets roll upward; most pronounced rolling is at the base of the leaflet. In varieties with red pigment, the base of the leaflet is reddish purple. Side branches swollen at the base. Brown flecks on the pith of lower part of stem. Plant wilts and dies prematurely-------------------------------- Purple-top wilt (p. 45).

B. Foliage showing dead areas but no wilting.

- (a) Leaves show dead spots with concentric rings, producing a target board effect------------------------------ Early blight (p. 30).
- (b) Dark-brown to black, irregular, usually fast-growing spots on leaves. Spreads rapidly. In severe cases, both leaves and stems are killed. Decayed tissue produces noticeable odor. White mildew usually present on underside of affected leaves and stems----------------------------------- Late blight (p. 28).
- (c) Drying and dying of the leaves, beginning at the tips and margins and working inward. Leaves present a scorched appearance. Tipburn and hopperburn (p. 32).
- (d) Small dead angular patches on the leaves; veins show black streaks underneath. Many of the leaves die and droop or drop off entirely. Rugose mosaic (current season infection) (p. 36).

C. Leaves rolling; usually soft or leathery. Shoots arising in the leaf axils swollen at base. No wilting, or wilting only late in the season.

(a) Young leaves fail to enlarge normally and the leaflets roll upward. Most pronounced rolling is at the base of the leaflets. In varieties with red pigment, the base of the leaflet is reddish purple. Side branches swollen at the base. Brownish flecks in the pith of lower part of stem. Plant wilts and dies prematurely.
Purple-top wilt (p. 45).

(b) Basal rolling or cupping of the young leaves. Rolled portions frequently assume purplish color. Axillary buds develop into shoots that frequently branch, giving plant a pyramidal shape. Formation of aerial tubers---------- Psyllid yellows (p. 44).

(c) Lesions or dead (dark-brown) areas on the underground stems. Upper leaves show rolling, but leaves are soft. Enlarged nodes or joints on stems common. Sometimes slight whitish fungus growth on green stems a short distance above soil line. Tubers show black sclerotia varying in size scattered irregularly over the surface--------- Rhizoctonia canker (black scurf) (p. 21).

(d) Upward rolling of the leaflets. Lower leaves rolled and leathery. Plants are yellowish green and considerably dwarfed. No swelling along stems--------------------------- Leaf roll (p. 37).

(e) Leaflets stiff, rolled, pointed, slightly yellowish. Petioles and stems may show swelling at the nodes. Tubers are lacking or few, and set close to the stem------------- Haywire (p. 42).

D. Mottled; yellowish or pale-green spots of varying size interspersed with normal green of foliage. Slight dwarfing of plant; no wilting.

(a) Yellowish areas alternate with the normal green of leaves. Surface of leaves is slightly crinkled. Stems are normal.
Mild mosaic (p. 35).

(b) Mottled areas smaller than in mild mosaic. Veins of the lower leaves show dead streaks or areas and are brittle. Surface and margin of leaflets usually quite uneven or crinkled.
Rugose mosaic (p. 36).

(c) Leaves show large irregular cream-colored spots or patches. Leaves not crinkled----------------------------------- Calico (p. 42).

E. Leaves small and velvety. Stems numerous and spindling. Plants dwarfed. Tubers small and abundant--------- Witches'-broom (p. 38).

F. Side shoots forming a sharp angle with the main stem, giving the plant a stiff and erect appearance. Leaves slightly rolled and somewhat darker green than on healthy plants. Tubers are spindle-shaped with stem end pointed-- Spindle tuber (p. 37).

G. Plant top normal or moderately checked. Roots show small swellings scattered irregularly over entire root system. Some tubers in hill show slight or distinct pustules on the surface and internal brown spots with pearly white centers as small as pinheads just beneath these pustules.
Root knot (nematode gall) (p. 31).

H. Leaves turn yellowish green; shoot often dies from tip downward. Rusty colored specks in the pith and outer layer of upper part of stalk and in the tubers. Tubers small and often cracked---- Yellow dwarf (p. 38).

Diseases Affecting Tubers.

A. Spots, eruptions, or cavities on the exterior of the tuber; interior normal or showing blotches or discoloration. No rot.

(a) Hard black to brown particles generally varying in size from a pinhead to one-eighth inch, adhering firmly to the skin of the tuber. Resemble spots of dirt but cannot be washed off.
Rhizoctonia canker (black scurf) (p. 21).

(b) Brown, rounded or irregular, corky, rough spots on the surface of the tuber. Spots vary in size and depth-- Common scab (p. 18).

(c) Spots nearly circular in shape; are at first blisterlike but later break open, forming roundish, raised pustules and exposing a powdery mass of spores surrounded on the edge by fringed remnants of the skin----------------- Powdery scab (p. 20).

(d) Warty, cauliflowerlike outgrowths originating at the eyes of the tubers. Warts first have the color of the affected parts of the potato, but after decay sets in turn dark brown or black.
Wart (p. 17).

(e) Small, slightly raised pustulelike elevations on the surface of the tuber; at times the galls or swellings may become very large and

the tuber takes on a knotty appearance. Beneath these elevations are small circular brown spots with pearly white centers. Root knot (nematode gall) (p. 31).

(f) Irregular brownish stained areas on skin of tuber, which turn silvery and show many fine black points when moistened. Silver scurf (p. 25).

(g) Whitish, soft, pustulelike swellings with openings; filled with light or cream-colored growth of cells. They usually harden and turn brown---------------------------- Enlarged lenticels (p. 51).

(h) Slight pustules or narrow furrows, with slivers of corky tissue under pimples, penetrating from ¼ to 1 inch into the tuber. Flea beetle injury (p. 33).

(i) Dark sunken areas of various shapes, sometimes surrounded by irregular raised borders of a gun-metal hue. Spots are generally shallow but may become deep, and cover an area from one-fourth to one-half inch in diameter. Tissue beyond the edge has a light-yellow discoloration---------- Early blight (p. 30).

(j) Browning of the vascular ring tissues of the tubers. *Fusarium oxysporum* wilt or verticillium wilt (p. 23).

(k) Browning of the vascular ring tissues of the tubers, and brown spots in the flesh------------- *Fusarium eumartii* wilt (p. 23).

(l) Brown to black discoloration of vascular tissue, usually limited to layer, less than one-fourth inch thick, sliced off at stem end. Stem-end browning (p. 25).

(m) Network of dead fibers, brown to dark brown, at stem end; vascular ring not affected. It may be limited to only a small portion or it may extend throughout the flesh of the tuber. Usually extends beyond layer, one-half inch thick, sliced off end------------------------------------ Net necrosis (p. 37).

(n) Brown discoloration of vascular ring and flesh between ring and tuber surface--------------- Heat and drought necrosis (p. 47).

(o) Irregular, dry, brown spots or blotches scattered through the flesh of the potato------------------ Internal brown spot (p. 46).

(p) Decided discoloration of the interior of the tuber. More or less blackening of the water vessels, and the finer strands extending into the pith and outer tissues; or irregular patches, gray to sooty black found generally in vascular ring and in the flesh outside of this------------- Frost or freezing necrosis (p. 47).

(q) Outer skin and flesh deep green, underlying flesh deep yellow. Tubers eventually become watery and turn brown throughout--------------------------------------- Sunscald (p. 48).

(r) Irregular area of black and leathery tissue in the interior of the tuber---------------------------------- Blackheart (p. 49).

(s) Irregular cavity in the center of the tuber. It varies in size and is lined by a thin brown layer of dead cells of the potato--------------------------------- Hollow heart (p. 50).

B. Rots showing on the exterior or interior of tuber, or both.

(a) Decided discoloration of the interior of the tuber. More or less blackening of the water vessels and the finer strands extending into the inner and outer tissues; or irregular patches, gray to sooty black, found generally in vascular tissue and in the tissues outside of these. Rot caused by bacteria or fungi often follows-------------------- Frost or freezing necrosis (p. 47).

(b) Decay, brown in color, ordinarily shallow; but may spread irregularly from the surface through the flesh. Under storage conditions this decay may be followed by soft rot or dry rot due to other organisms------------------------ Late blight (p. 28).

(c) Sunken areas of brown firm rot, often involving large part of tuber. Affected portion of tuber wrinkled and bearing bluish or white protuberances------------------------ Dry rot (p. 26).

(d) Center of tuber rots faster than the outer tissues; cavities filled with a pink, powdery, fungus growth. Pinkish or white tufts of fungus growth on wrinkled exterior-- Powdery dry rot (p. 26).

(e) Surface of decaying tuber covered with white fungus threads and brownish, hard, round, seedlike bodies resembling mustard seed. Interior of tuber shows a white, odorless decay but later turns into a liquid stage-- Sclerotium rot (southern blight) (p. 15).

(f) A jellylike rot at the stem end of long potatoes, such as Burbank and White Rose________________________ Jelly-end rot (p. 16).

(g) Internal tissue granular and extremely watery; upon cutting may turn black. When pressure is applied a yellowish to brown liquid is given off. External tissue appears firm and may be metallic gray to brown______________________________ Leak (p. 13).

(h) Rot white or buttery in consistency; gradually turns black and slimy; generally develops a foul odor_______ Blackleg (p. 6).

(i) Rot in the vascular ring, creamy, yellow or reddish brown, crumbly or cheesy, and odorless; may extend later into inner and outer tissue. In early stages tissue may be turgid with intercellular spaces full of bacteria. The external effect is a reddish-brown discoloration. Tubers are often cracked.
Ring rot (bacterial ring rot) (p. 10).

(j) Bacterial ooze and dirt stick to eyes of the tuber. Vascular ring shows a dark-brown discoloration. Upon cutting the browned strands, drops of sticky, milky-white exudate appear. Slimy soft rot may develop later_____ Brown rot (bacterial wilt) (p. 8).

C. Tubers or sprouts abnormal in shape, but free from spots and rots.

(a) Sprouts of tubers abnormally slender and feeble. Spindling sprout (hair sprout) (p. 49). Witches'-broom (p. 38). Leaf roll (p. 37).

(b) New potatoes instead of sprouts are formed on the surface of the old tuber______________________________ Sprout tubers (p. 52).

(c) Long tubers abnormally spindling, elongated, and pointed at the stem end. Oval tubers elongated, tending notably to be blocky cylindrical in shape__________________ Spindle tuber (p. 37).

(d) Second growth, or knobs on tubers. The knobs are easily broken off_________________ Second growth (knobby tubers) (p. 51).

DISEASES DUE TO PARASITES

Blackleg

Blackleg (*Erwinia phytophthora* (Appel) Bergey et al.) is a bacterial disease that in some years causes heavy losses in some of the potato-growing sections. It may be responsible for missing hills, when it destroys the sprouts before they appear above ground or causes the seed piece to rot before sprouts have started. It is the cause of serious rotting of tubers in storage (fig. 1). The first symptoms are

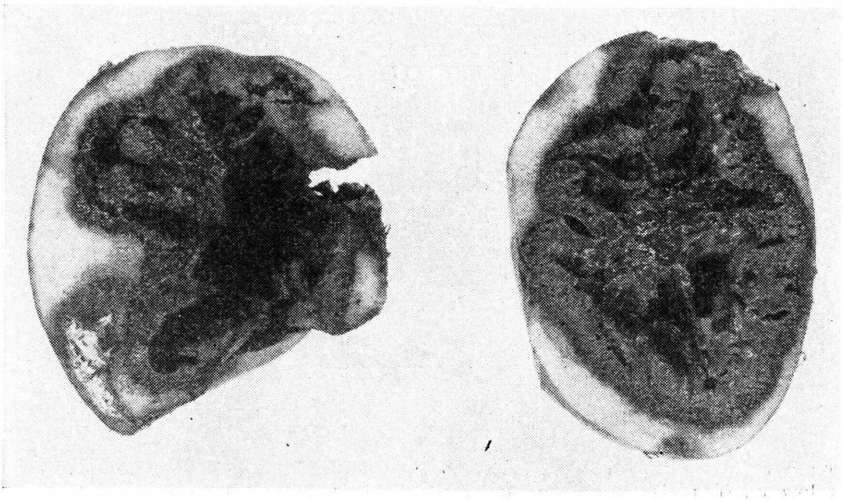

FIGURE 1.—Advanced stage of blackleg in potato tubers.

the rolling of the upper leaves of one or more shoots, compactness of such foliage, and the gradual fading of the deep-green color of the foliage into yellow green; later on, the plants assume a distinct yellow color. The plant gradually dies as the base of the stem is rotted away by the bacteria. The diagnosis of the disease in the field is readily confirmed by pulling the affected plants. The stems, already considerably rotted, offer no resistance to pulling and have an inky-black appearance or are mushy and green. Seasons of abnormal rainfall are very favorable for the bacterial growth, and the disease progresses rapidly involving more of the top than in dry seasons.

Under less favorable conditions, when the disease progresses very slowly, aerial tubers may be formed on the stems (fig. 2), as in the case of rhizoctonia canker. Plants less severely attacked, or not affected until later in the season, produce potatoes that if harvested and planted are very likely to carry the disease over to the next season. From experiments made in Oregon, 60 percent blackleg was obtained when apparently sound tubers from blackleg-infected hills were planted, whereas tubers from healthy plants failed to develop the disease. Unless the conditions for development of blackleg are favorable, however, the disease will not occur even if infected tubers are planted.

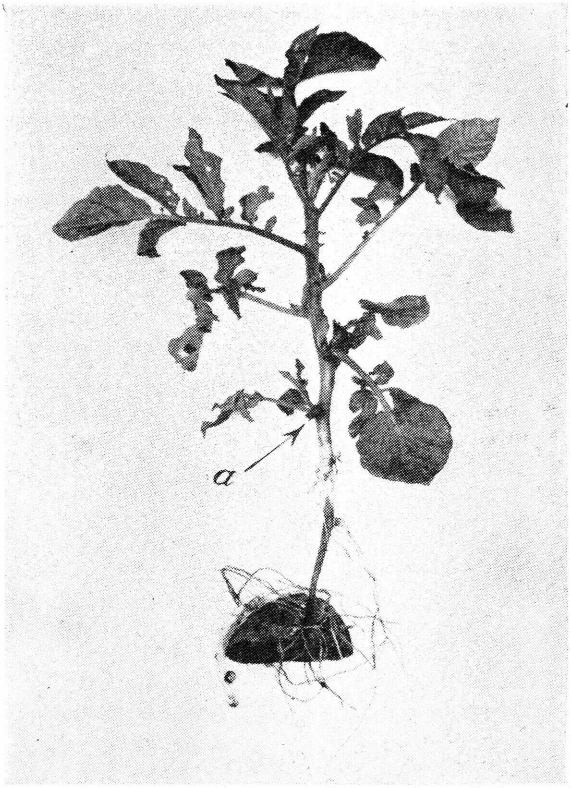

FIGURE 2.—Potato plant showing blackleg infection. Notice the blackening of the lower part of the stem and the formation of aerial tubers (*a*). (By courtesy of the Minnesota Agricultural Experiment Station.)

In Minnesota and Maine it has been demonstrated that the seed-corn maggot is active in spreading the disease among plants. If the fly has access to seed potatoes before planting, eggs may be deposited, which, on hatching, are often contaminated with the blackleg organism.

To control blackleg, only tubers from fields in which the disease has not occurred should be planted.

Brown Rot (Bacterial Wilt)

Brown rot (*Phytomonas solanacearum* (E. F. Smith) Bergy et al.) is also known as southern bacterial wilt. Climatic conditions limit the common occurrence of brown rot in the United States to localities in the South Atlantic and Gulf Coast States from Maryland to Texas, and in Ohio, Illinois, West Virginia, and Kentucky. It differs in this respect from ring rot (p. 10), as climatic conditions apparently do not limit the distribution of the latter disease.

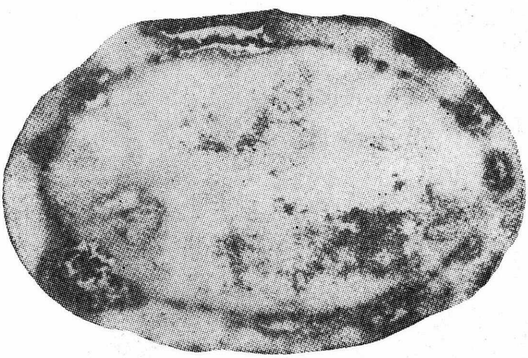

FIGURE 3.—A potato affected with brown rot or bacterial wilt.

The first symptom of the disease to appear in the potato plant is a slight wilting of the leaves at the ends of the branches during the hottest period of the day. Affected plants recover during the night, but the wilting becomes more pronounced each day until finally the plants die.

The vascular bundles in the stems, roots, and stolons turn brown when they become clogged with bacteria, which cause the wilting and death by cutting off the plant's water supply (fig. 3). The brown color is finally evident on the outer surface of these parts and may be seen on the stem of severely affected plants 1 or more inches above the soil line. When the vascular bundles of the affected parts are cut or broken the bacteria ooze from them as a white slimy mass.

In the tuber the vascular area is first invaded by the bacteria, and when the disease has developed to a certain stage the brown color of the affected tissues near the surface can be seen, particularly around the stem and eyes. The bacterial ooze exudes from the eyes and stem end of the severely diseased tuber, and may become mixed with dirt which, when dried, sticks to the surface of the tuber (fig. 4). If left in the ground the tubers continue to decay; the bacteria destroy the tissue that surrounds the vascular ring and finally break through the skin. Other rot organisms enter the tuber at this stage and assist in making it a slimy mass with an offensive odor.

Plants with their tops killed by brown rot may bear healthy as well as diseased tubers. Other plants showing no signs of the disease in their tops may sometimes produce diseased tubers. The distinctions

between this disease and the ring rot are outlined in the discussion of the latter (p. 10).

As seed potatoes used in most sections of the United States are produced in localities where brown rot does not occur, the disease is usually not carried in the seed. Because so many weeds are host plants of *Phytomonas solanacearum*, it would be impracticable to attempt to eliminate brown rot from potato land by crop rotation or weed eradication. The Green Mountain and Katahdin varieties are

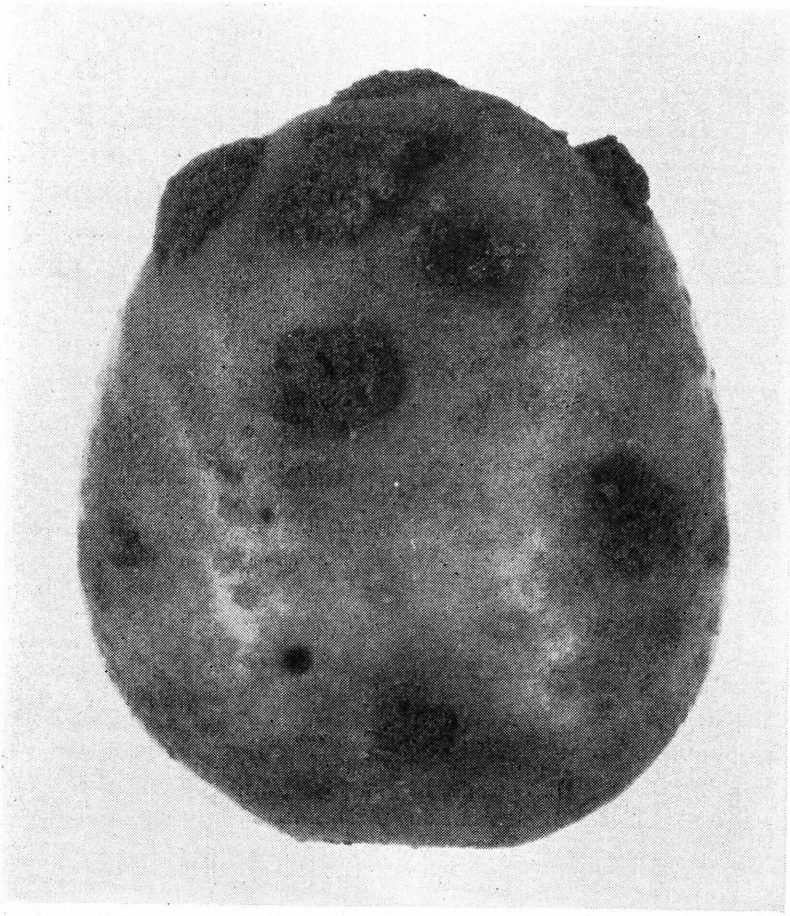

FIGURE 4.—A Spaulding Rose tuber affected with brown rot, showing bacterial exudate and dirt sticking to the eyes of the tuber. (By courtesy of the Florida Agricultural Experiment Station.)

much more resistant to this disease than Spaulding Rose, Irish Cobbler, or Triumph.

Experiments in Florida have shown that in sandy types of soil, brown rot can be controlled by an application of 800 pounds of sulfur to the acre in the summer, followed by 3,000 pounds of limestone to the acre in the fall. This treatment is not recommended on muck, peat, loam, or clay types of soil.

Ring Rot (Bacterial Ring Rot)

Ring rot (bacterial ring rot) (*Phytomonas sepedonica* (Spieckermann) Magrou), an extremely infectious bacterial wilt and ring rot disease, is a recent introduction and has been noted in this country only since about 1934. It is now present in nearly all potato-growing States. The symptoms of this disease generally do not become evident until late in the growing season. Some plants become infected without ever showing symptoms in the leaves. In other cases one or more stems in a hill may wilt and be more or less stunted, whereas the remainder

FIGURE 5.—A potato plant affected with ring rot, showing wilted branches and leaves. (By courtesy of the Florida Agricultural Experiment Station.)

appear healthy (fig. 5). When affected plants are dug, there are usually found all gradations from sound to completely decayed tubers. The decay begins in the region near the vascular ring of the tuber. It may affect any part or all of the ring, in the latter case causing a ring rot appearance. The decayed tissue is yellowish white and of a crumbly nature (fig. 6). This decayed material may ooze from the infected vascular ring if the tuber is squeezed in the hand. Some severely affected tubers may have cracks or reddish discolorations on the skin. The cracks extend only to the vascular ring. Infected tubers are often invaded by other soft rot organisms that break down the tuber more completely.

The organism lives over winter in slightly affected tubers. A high percentage of the tubers harvested from wilted plants will produce the disease when planted the following year. The bacteria overwinter chiefly on slightly affected tubers. In many of these tubers the disease cannot be detected; yet they contain sufficient bacteria to contaminate the knife and planter and these in turn inoculate healthy sets. Bacteria from decayed tubers smeared on healthy tubers may remain alive in the dry state all winter and bring about infection when the tubers are being cut into sets. The disease may spread also from diseased plants to healthy ones in the field. There is no definite proof that the organism will remain alive in the soil over winter. Although there is no proof that it is soil borne, growers should avoid planting their healthy seed stocks in any field that produced a crop having ring rot

FIGURE 6.—A tuber affected with ring rot, sliced lengthwise to show the extent of decay and the separation of the cortex tissue from the core of the tuber. (By courtesy of the Florida Agricultural Experiment Station.)

the previous year. Volunteer plants in such fields may possibly perpetuate the disease.

Ring rot and brown rot (p. 8) can be differentiated by certain contrasting symptoms. Ring rot causes mottling in the leaf as the color fades to a pale green then to a pale yellow, which is followed by the development of brown necrotic areas, usually at the margin; the leaf rolls upward as it wilts and dies (fig. 7). Brown rot causes the wilted leaf to fade to a pale green, after which it dies and turns brown without mottling or rolling. Ring rot does not produce any stem symptoms. Brown rot causes a brown discoloration of the vascular bundles which when cut exude the causal bacteria. Both diseases cause a *ring rot* of the tuber and, in advanced stages, discolor the skin at the stolon end, at the eyes, and at other places. Ring rot causes a reddish-brown dis-

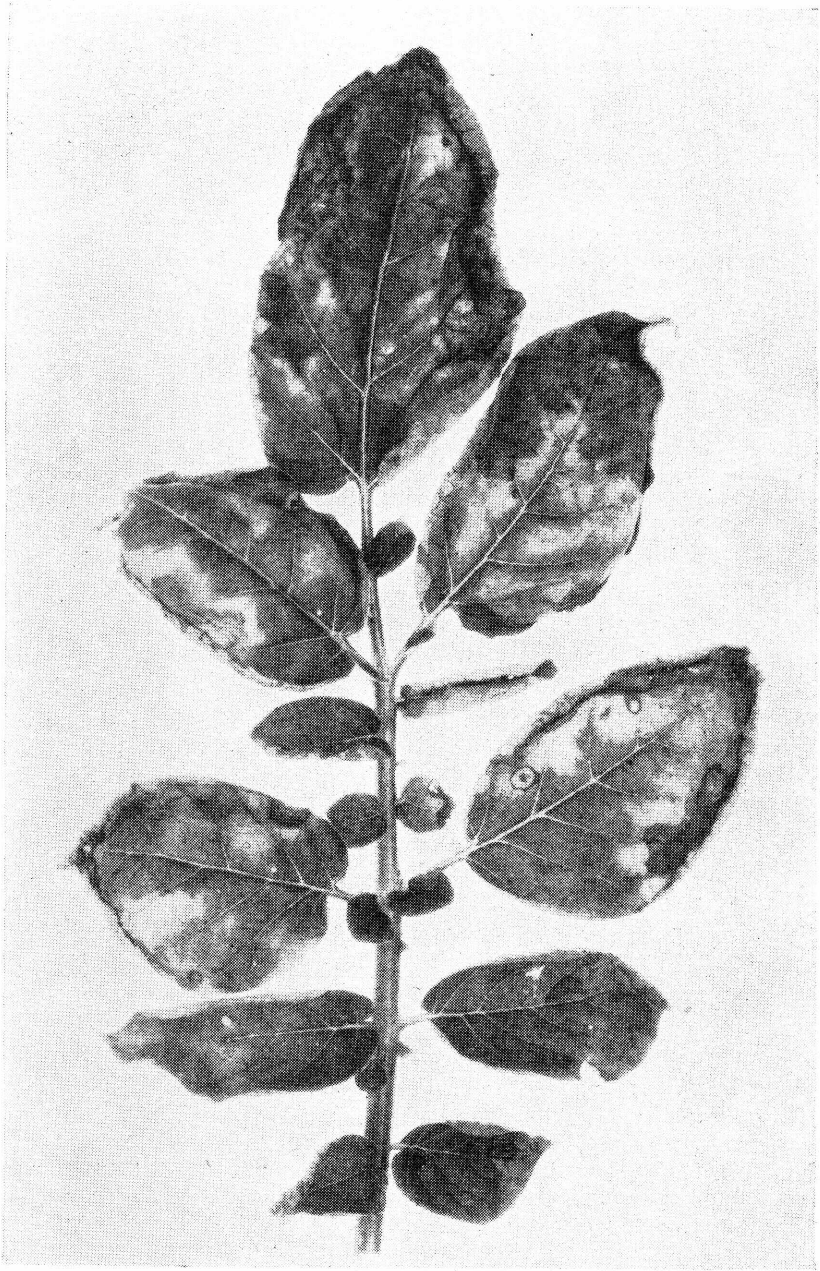

FIGURE 7.—Wilted leaf from a potato plant infected with ring rot, showing characteristic chlorotic and necrotic areas in leaves and rolling at tips of leaves. (By courtesy of the Florida Agricultural Experiment Station.)

coloration of the tuber skin, which may be accompanied by cracking; in some tubers, particularly those kept in storage several weeks, the skin and outer flesh also occasionally crack and separate from the remainder of the tuber. Brown rot produces a brown to black discoloration of the affected tissues with no trace of red and no cracking of the skin or separation of parts of the tuber.

White sticky masses of the brown rot bacteria ooze from the stolon end and the eyes of the diseased tuber, where they may become mixed with dirt and on drying are glued to the surface of the tuber; the ring rot bacteria are not sticky and do not ooze from the tuber.

Each disease may cause decay of any part or all of the vascular sections of the tuber; however, brown rot is usually confined to the vascular area and to tissues immediately adjacent, thus producing a marked ring appearance that is not so conspicuous in tubers affected with ring rot. The tissues affected with ring rot are soft and crumbly and are gray, cream, yellow, or reddish brown; those decayed by brown rot are slimy and of a brown to black color. The bacterial ooze from the vascular strands of a freshly dug tuber that has been sliced is characteristic of brown rot, but not of ring rot.

The only practical method of controlling the ring rot disease is by the exclusive use of disease-free seed stock. This disease increases very rapidly, and experiments conducted in Maine have shown that a crop having a mere trace of the disease in one season may have from 10 to 30 percent the following year. Seed-producing States will not certify any fields that contain even a trace of ring rot. Sometimes such stock is sold and used for seed purposes but not as certified seed. Such a practice should be discouraged, because it will defeat the purposes of control through certification.

The use of whole tubers is recommended to eliminate spread due to cutting and handling freshly cut seed potatoes. If ring rot has been present on the farm or in a storage cellar, all containers used for potatoes should be thoroughly disinfected with formaldehyde, 1 pint to 15 gallons of water, or new bags and crates should be used. Planters, diggers, graders, and other equipment should be disinfected with lysol—2½ teaspoons per gallon of water.

Leak

The most characteristic symptom of leak (*Pythium debaryanum* Hesse) is the extremely watery nature of affected tissues. The water usually is held by the disintegrated tissues, but when pressure is applied a yellowish to brown liquid is given off readily. Another characteristic symptom is the granular nature of the diseased tissues.

Externally, the affected tissues appear turgid and may show discoloration ranging from a metallic gray in the red varieties to brown shades in the white- and dark-skinned varieties (fig. 8). Internally, the affected tissues are at first creamy in color; upon cutting, as well as in the later stages of the disease, they soon turn tan or slightly reddish and then become brown and finally inky black. The diseased areas generally are sharply set off from the healthy tissue. There rarely is a discernible fungus growth externally or internally, nor are these cavities lined by white or brightly colored molds, as in the soft types of fusarium rot, which resemble leak. The colors of leak resemble those

of blackheart affected tissues, but the latter do not become soft, watery, and granular.

Tubers become contaminated in the field, where the organisms live as soil fungi. Infection takes place during hot weather and apparently only through wounds, though these need not be visible. Leak frequently is found in tubers affected with sunburn or scald, especially when these occur in tubers allowed to lie in or on hot soils after being dug. In potato crops that are harvested and moved during extremely

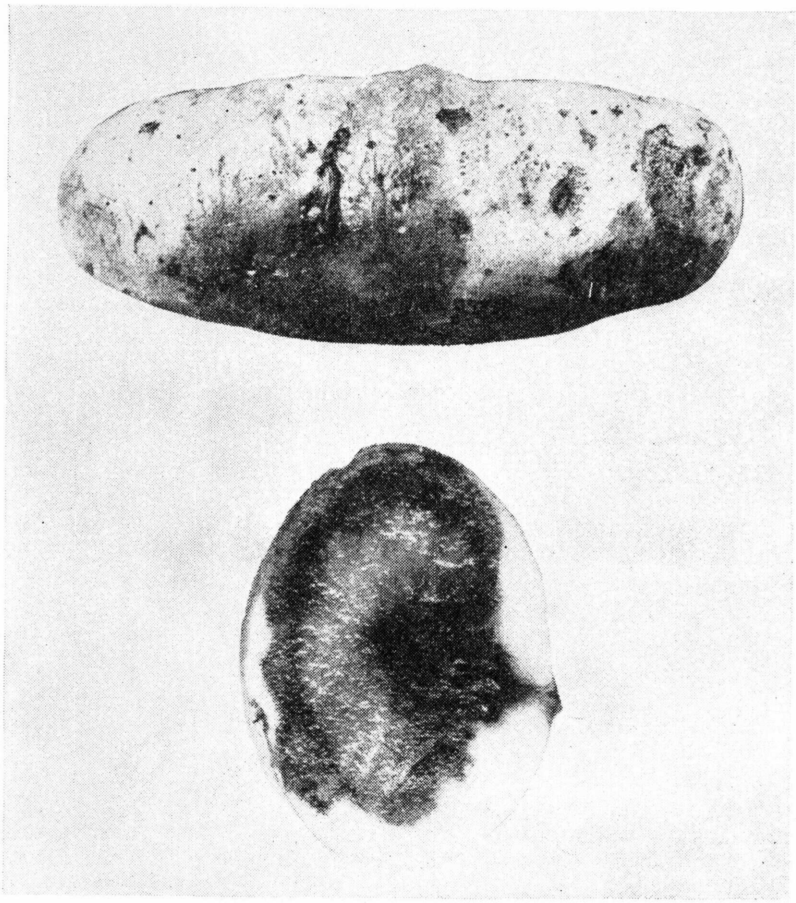

FIGURE 8.—Potato affected with leak.

warm weather, such as the early crop of Idaho and Washington and the crop grown in the upper San Joaquin Valley of California, leak may be serious, but the trouble has not been common during the past few years, due perhaps to better handling of the crop. In other sections it seems to occur only if there is abnormally warm weather during the digging, moving, and early storage of the crop.

When infection has once taken place the disease progresses very rapidly and develops in contaminated tubers even in refrigerator cars. At temperatures between 60° and 90° F. the disease progresses so

rapidly that lesions become visible within 36 hours after infection. At temperatures above 50°, leak lesions usually are invaded by bacteria, which check the growth of the organism causing leak and produce foul-smelling, sticky, or slimy decays.

Control involves keeping tubers as cool and dry as possible during harvesting and loading as well as in the early stages of transit and storage, and avoiding injury to the skin.

Sclerotium Rot (Southern Blight)

Sclerotium rot (southern blight) (*Sclerotium rolfsii* Sacc.) is essentially a disease of truck crops of the southern part of the United States. It attacks potato vines in the field, producing a rapid decay of the stems at the surface of the ground. It also produces a very rapid tuber rot if conditions are favorable. This rot is a white and prac-

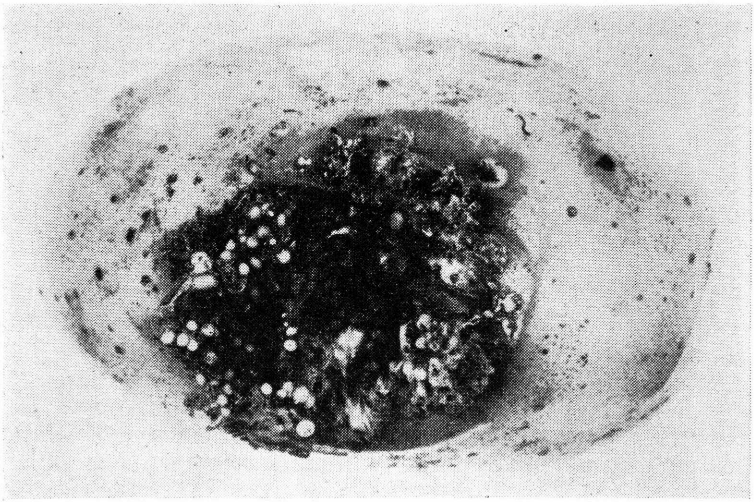

FIGURE 9.—Tuber rotted by *Sclerotium rolfsii* at stem end. Note sclerotia of the fungus on the dirt clinging to the stem end. (By courtesy of the Florida Agricultural Experiment Station.)

tically odorless decay in the first stages, but later it takes on a yellowish color. In mild cases there are only slightly sunken spots, the soft, decaying material of which can be separated easily from the healthy by pressure. In severe cases the entire contents of the tuber are turned into a liquid. The surface of the decaying potato is covered with fine fungus threads and hard, round, seedlike bodies resembling mustard seed (figs. 9 and 10). When scattered in the soil, they germinate under favorable conditions and infect new crops.

No practicable way to exterminate the fungus from the soil is known. Destruction of diseased plants in the field should be practiced in order to reduce the amount of soil infection. When storing the early southern potatoes is necessary, good storage conditions will check the development of the decay.

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FIGURE 10.—The same tuber as that shown in figure 9 sectioned to show rot carried by *Sclerotium rolfsii* and the presence of the mycelium of this fungus in the decayed area. (By courtesy of the Florida Agricultural Experiment Station.)

Jelly-End Rot

Jelly-end rot (*Fusarium* sp.) gives the affected parts of the potato a jellylike consistency. Long potatoes like Burbank and Netted Gem, grown especially on the Pacific coast, are subject to this disease. It varies widely in type and extent of rot at harvest time, from slight withering to a dry, wrinkled, sunken, and rather tough condition, and from no evident discoloration to a light-brown or black discoloration involving a half inch or more of the stem end of the tuber. At times there is a soft and rather jellylike light-brown rot extending back as much as 1½ inches from the stem end, the rest of the tuber being sound and unaffected (fig. 11). In storage the diseased tubers often do not rot further unless stored under unfavorable conditions.

FIGURE 11.—Pointed-end Netted Gem potato affected with jelly-end rot.

The affected tissues frequently dry down, forming a sharp line of demarcation between the sound and healthy tissues. The exact conditions that lead to the development of the rot are not known, but it seems possible that when moisture in the soil is deficient in the latter part of the growing season the plant may actually withdraw water from the stem end of the tuber. This brings about a sunken, withered condition favorable to the entrance of various organisms both saprophytic and parasitic, and rot soon follows. No organism is found consistently associated with the disease, and the rot develops in the crop without any apparent relation to the condition of the seed potatoes at planting time.

No special measures for the control of jelly-end rot can be definitely recommended. However, the rot can no doubt be avoided to a considerable extent by the maintenance of a uniform and adequate supply of moisture in the soil throughout the season.

Wart

Wart (*Synchytrium endobioticum* (Schilb.) Perc.) was introduced into eastern North America about 1912 and is found only in limited districts in Pennsylvania, Maryland, and West Virginia, where it is mostly confined to small gardens. It has caused serious damage for many years in Europe, especially in certain districts of England and Ireland.

The disease is characterized by warty outgrowths on the underground portions of the plant. These vary greatly in size (fig. 12), and sometimes the entire tuber is converted into a spongy, warty mass. The warts occur abundantly on the tubers (fig. 13), stolons, and underground portions of the main stem. When this wart-affected tissue is left in the soil, it soon becomes broken up and liberates millions of spores, leaving the land badly infested for years.

Experiments carried on in Pennsylvania have shown that when wart-infested soil is kept in sod, the organism may remain active in the soil for over 20 years. If the soil is planted with nonsusceptible crops and is cultivated regularly, the organism gradually disappears from the soil during a period of about 10 years or even less. A thorough eradication program is now being conducted by the Pennsylvania Department of Agriculture. Infested soil is treated with ammonium thiocyanate at the rate of 2,000 pounds per acre or with flaked copper sulfate at the rate of 2,500 pounds per acre. Treated gardens are then planted with susceptible potato varieties, and each tuber is thoroughly examined at digging time for the presence of the wart disease. If, during a period of 5 years wart fails to develop in treated plots, it is assumed that the wart has been completely eradicated. It is believed that by carrying on a thorough eradication program eventually wart will be entirely eliminated from the State of Pennsylvania.

The potato, the nightshade (*Solanum nigrum* L.), the true bittersweet (*S. dulcamara* L.), and under some conditions the tomato, are the only plants known to be attacked by the wart disease.

The chief and most reliable means of control is the use of immune varieties of potatoes, such as Spaulding Rose, Green Mountain, Irish Cobbler, and Burbank.

Common Scab

Common scab (*Actinomyces scabies* (Thax.) Güssow) is known to exist in every potato-growing section of the United States. It is confined entirely to the tubers. Usually the spots are small and brownish at first but later enlarge into hard, circular, or irregular corky areas on the surface of the tuber. The scab lesions may be separate or may run together sometimes to the extent of covering the entire tuber. Common scab lesions vary in type from deep to shallow or even raised

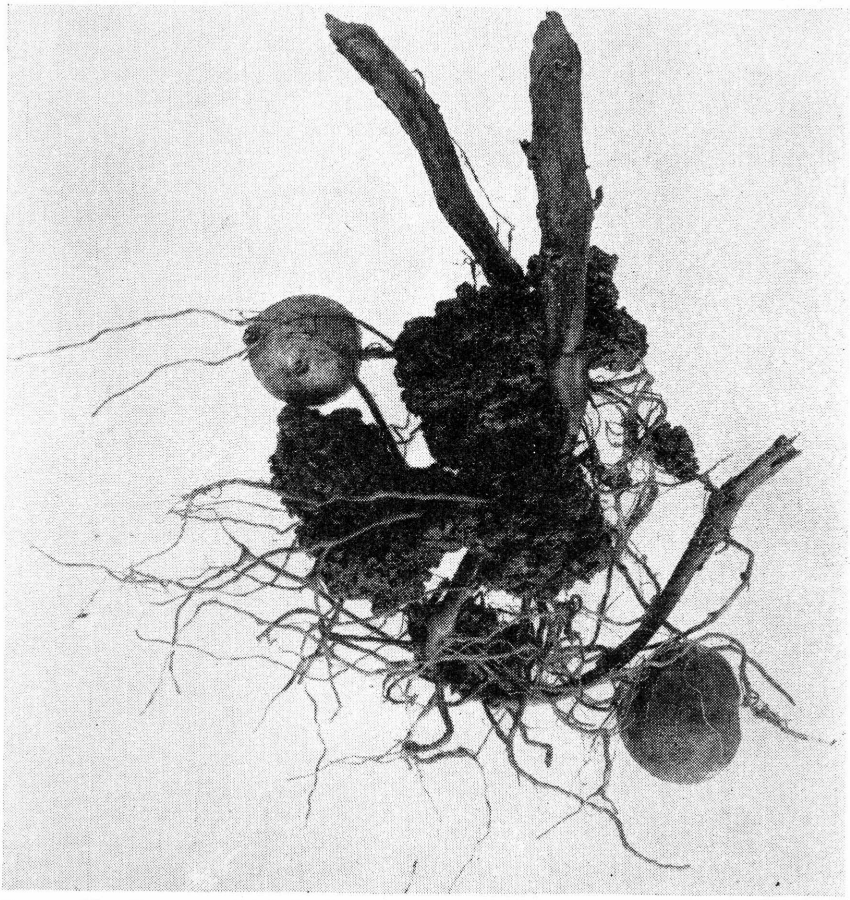

FIGURE 12.—Severe wart infection on the underground stem of a potato plant.

forms (fig. 14). Scab is particularly severe in alkaline soils or in soils that are about neutral but causes little if any damage in acid soils. Some alkaline soils in Nebraska and New York have been reported to have less scab than soils about neutral. The causal organism persists in the soil, and the infection of the new crop may come either from the infested soil or from diseased seed potatoes that have not been treated.

Scab lesions have sometimes been confused with abnormally enlarged lenticels. Flea-beetle injury, caused by the larvae of two

species of flea beetles, *Epitrix cucumeris* (Harr.) and *E. subcrinita* (Lec.) may also in some cases resemble the external appearance of the first stages of scab infection. However, when the pustules or furrows made by the flea-beetle larvae are cut through, peculiar tough splinters of corky tissue are found extending perpendicularly into the tuber. Not infrequently there is secondary infection with rhizoctonia canker and scab, which deepen the furrows and the insect feeding scars.

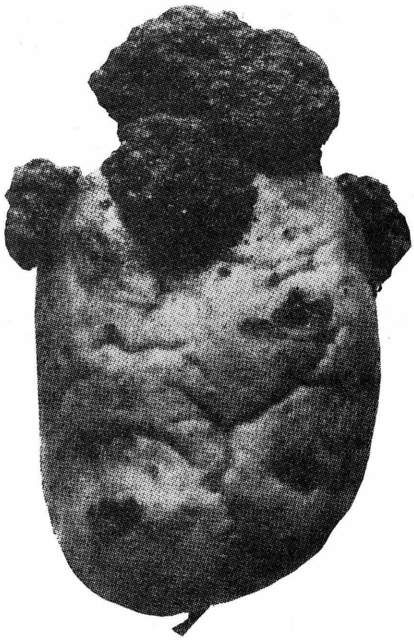

FIGURE 13.—A potato showing pronounced wart infection.

Grub and rodent injuries lead to the formation of large cavities which are seldom confused with scab. These cavities are free from the heavy corky incrustations so characteristic of both the deep and shallow forms of common scab.

Ordinarily scab develops best when the soil moisture is slightly below the requirement for optimum growth of the potato plant. If the soil is of such texture that there is abundant aeration, scab may develop readily even though the soil is very wet. In some of the Middle Western States peat soils are wet most of the growing season, and very severe scab develops in these soils.

The scab organism can be carried from one season to another in the scab spots on the tubers; therefore seed treatment appears to be the

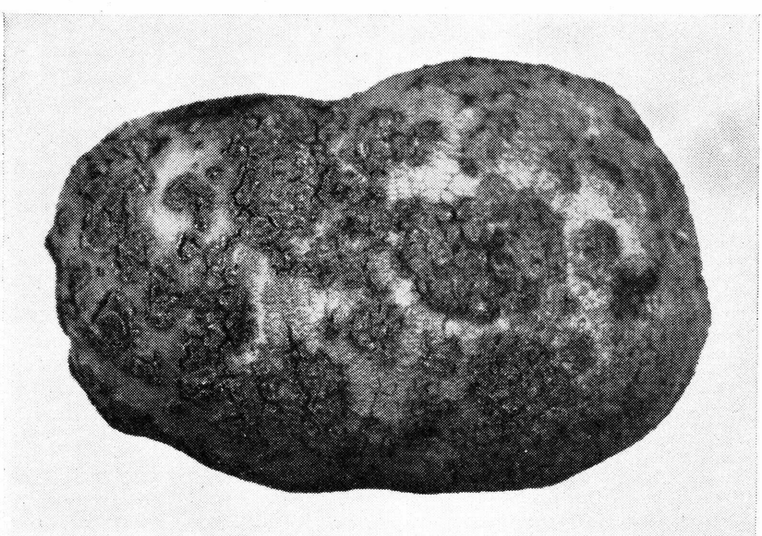

FIGURE 14.—A potato tuber showing severe infection with common scab.

most important means of control. However, seed treatment has not been uniformly successful in controlling scab in the succeeding crop, chiefly because the scab organism can live in the soil for a long time, especially if it is alkaline. Experiments in New York State indicated that all of the tested mercury compounds, whether organic or inorganic, when added to scab-infested soil, increase the percentage of scab in most up-State locations. If the soil is heavily infested the use of clean or disinfected seed will be of little value in preventing scab from developing on the new tubers. If the soil is acid, scab fails to develop even if badly infected seed is planted. Attempts to make alkaline soil acid by the application of sulfur at the rate of 300 to 600 pounds per acre have been most successful on the lighter types of soils, but even on these types the control has not been entirely satisfactory, although it has generally reduced somewhat the severity of scab infections.

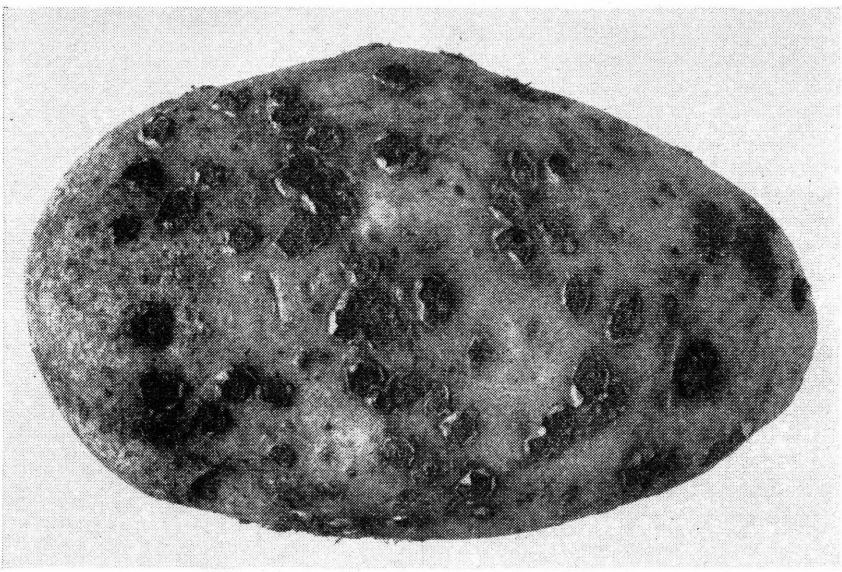

FIGURE 15.—A potato showing the mature stage of powdery scab.

The development and use of scab-resistant varieties appear to provide the best future possibility of successfully growing potatoes on scab-infested land.

Powdery Scab

The distribution of powdery scab (*Spongospora subterranea* (Wallr.) T. Johns.) in the United States is limited to moist, cool regions. It has been found in this country in a number of States from Maine to Minnesota and also in the coast counties of Oregon. The disease does not develop when the temperature is very high. So far it has not proved so serious in the United States as was at first feared; therefore, it does not seem to be a menace to the national potato industry. The disease resembles common scab somewhat in appearance, but the individual spots are more nearly circular in shape

and on an average are smaller in diameter. When fully mature, the open pustules are filled with a brown more or less powdery mass of spores and broken-down tissue and are surrounded on the edge by fringed remnants of the skin (fig. 15). In the immature stages these spots are closed and somewhat raised, and are dark on the outside and brown or olive brown on the inside. The fungus lives in the soil, and infection takes place during the growth of the tubers. Under some conditions the diseased seed tubers may introduce powdery scab into clean soils.

Powdery scab is not satisfactorily controlled by seed treatment. Affected tubers should not be used for seed purposes in localities with cool, moist climates. Long rotations are necessary to rid the soil of the organism when it once becomes established.

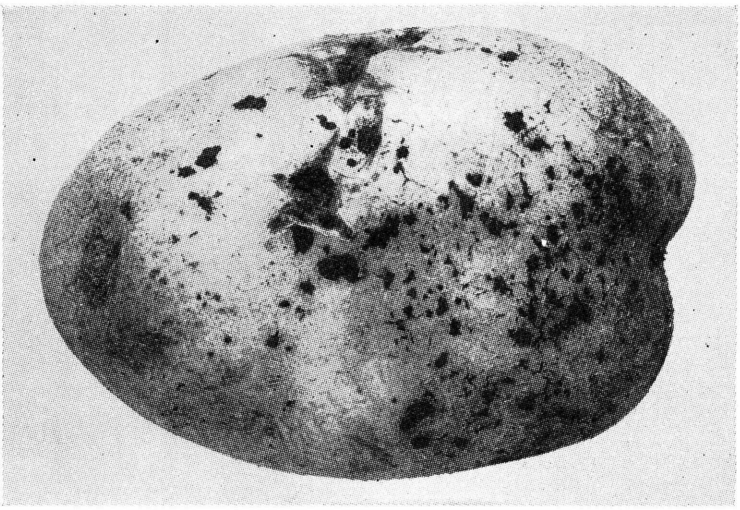

FIGURE 16.—Rhizoctonia canker. A potato covered with black sclerotia.

Rhizoctonia Canker (Black Scurf)

On the tuber, the fungus that causes rhizoctonia canker or black scurf (*Corticium solani* (Prill and Delacr.) Bourd. and Galz.) ordinarily shows as small brown-black bodies closely adhering to the skin. They may be as small as a pinhead or as large as a half pea (fig. 16). These particles, known as sclerotia, are composed of an extremely close weft of mycelial threads and represent the resting stage of the fungus. When introduced into the soil on seed tubers, these sclerotia produce an abundance of fungal threads that attack the young shoots, stolons, and tubers of the new crop. Often the sprouts are attacked and are burnt off by the fungus before they reach the surface of the ground. This may lead to the production of other new sprouts that in turn have their tips killed, with the result that a rosette or cluster of sprouts is formed, none of which reach the surface of the ground. This is often the cause of poor stands. When not so badly affected, the vines, although appearing late, may develop into a productive plant.

Lesions or dead areas may also develop on the underground stems and on the stolons (fig. 17), and these may so interfere with the normal growth and function of the plant that the leaves roll up considerably, small potatoes form in the axils of the leaves, or the nodes of the stem become considerably enlarged and knobby because the starch cannot be properly transported downward. Many small potatoes and a few

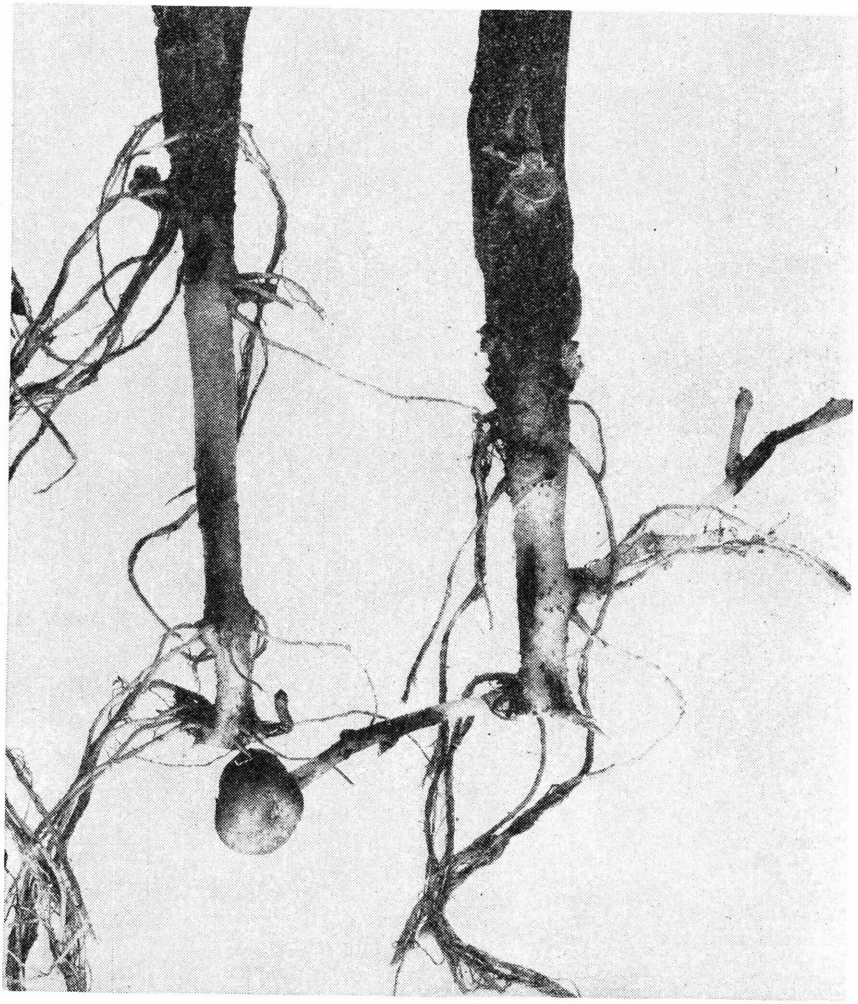

FIGURE 17.—Brown, dead, cankerous areas on stalks and on stolons due to rhizoctonia canker. Sometimes the stalks may be completely girdled.

large knotty ones may be developed underground. This result often gives rise to the term "little potato disease." As the sprouts are attacked by fungus growth proceeding from the sclerotia on the seed tubers, seed treatment reduces the amount of sprout rot.

Control consists in not using affected tubers for seed or in treating slightly affected seed tubers with mercuric chloride or other disinfectants, as discussed on page 58. As the organism also lives over

in the soil, crop rotation with nonsusceptible crops is advisable. Experiments conducted in New York State show that rhizoctonia injury was considerably reduced when a combination of commercial fertilizer, stable manure, and cover crops was used. Somewhat similar results were reported from the irrigated section of western Nebraska.

Wilt

Potato wilt is caused by *Verticillium albo-atrum* Reinke and Berth. and certain species of *Fusarium*. Either *F. oxysporum* Schl. or *F. eumartii* C. W. Carpenter, is usually associated with this disease, but recent work in Nebraska has shown that *F. solani* (Mart.) App. and Wr. may also be involved, and *F. avenaceum* (Fr.) Sacc. has been reported from Wisconsin as acting very much like *F. oxysporum*. In the Northern States *Verticillium albo-atrum* is often responsible for wilt. However, this organism does not attack plants growing at relatively high temperatures.

The symptoms on potato caused by *Fusarium oxysporum* and *Verticillium albo-atrum* are so familiar in appearance and effect that both may be treated together. Attacked plants may wilt rather suddenly and die in a comparatively short time (fig. 18), or they may show the effects slowly and succumb very gradually. Plants produced from infected tubers may be stunted from the beginning and die without attaining average size. Those contracting the disease from neighboring plants or from the soil show their first indication of the disease in the yellowing and drooping of the lower, older leaves. There may also be some curling and rolling of the leaflets and some tip burning. Such vines die prematurely, but the stalk remains upright, except for the tip which may droop. The yellowing and dying of the leaves proceeds from the base upwards until there is often only a cluster of green leaves at the top. On hot days this yellowing is preceded by a wilting of the leaves and even of the stalk. The stems of affected plants are invariably discolored in the interior. The woody tissues of the interior of the stem are yellow to brown, often extending from the base well into the top.

The tubers of wilt-infected plants often show a browning of the water vessels near the stem end. Discoloration of the vascular ring of the stems and tubers, indistinguishable from that caused by the wilt fungus, may be brought about by physiological conditions and cannot be relied on as a sure symptom of wilt. In Oregon when 12,000 tubers were examined in detail in the laboratory, only 45 percent of those that were browned in the stem-end vascular region gave organisms pathogenic for potatoes; 55 percent gave either no organisms or miscellaneous fungi of no apparent importance. Twenty-two percent of the tubers that were distinctly yellowed in the stem-end vascular region and 5 percent of those that showed no discoloration gave organisms parasitic on potato.

The wilt caused by *Fusarium eumartii* produces a burning and bronzing and slight yellowing of upper leaflets. In late stages the leaves wilt and die. Stems of the affected plants show a brownish flecking when cut longitudinally. Tubers of such plants show a browning of the stem end and vascular discoloration (fig. 19).

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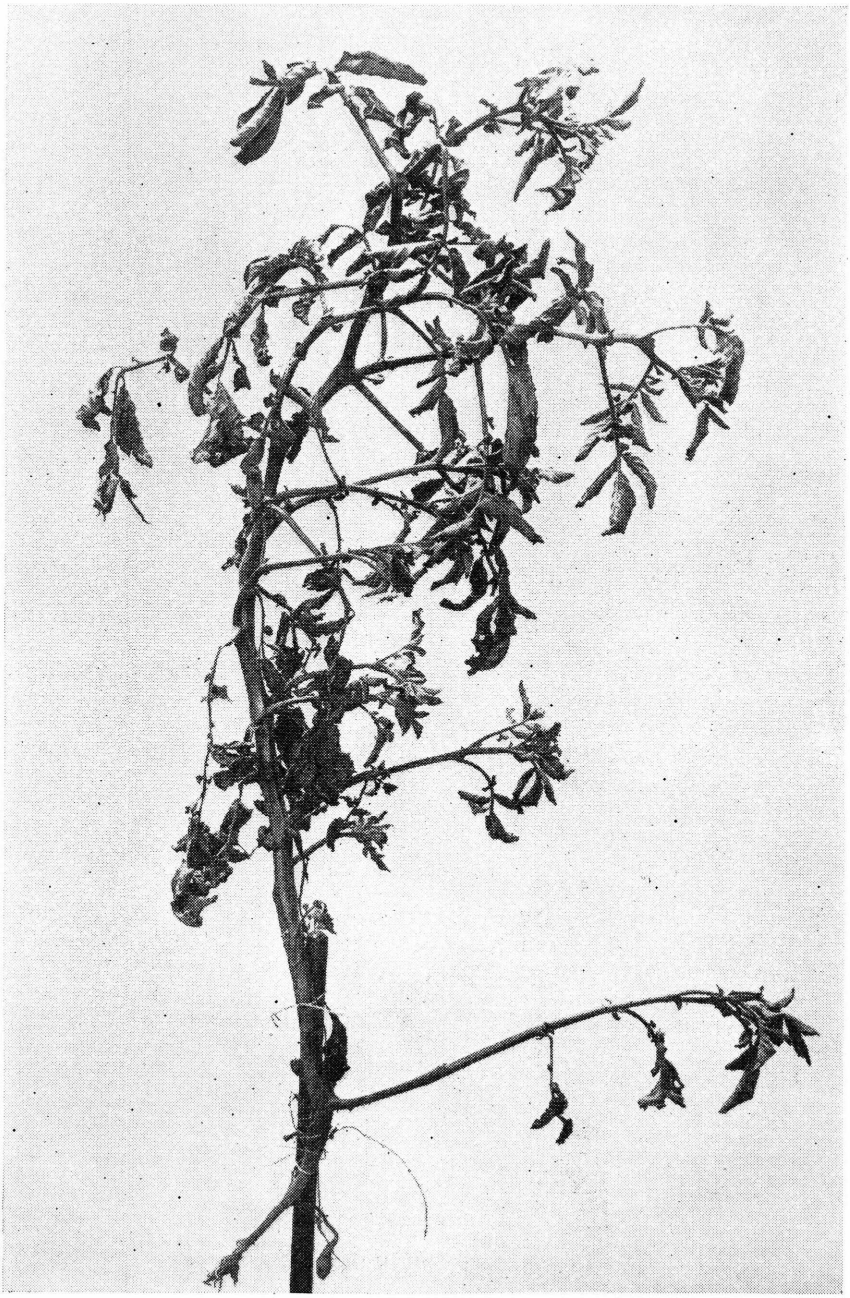

FIGURE 18.—Potato wilt caused by *Fusarium oxysporum*.

As wilt is carried over from one crop to another in seed potatoes and in the soil, seed selection and crop rotation are the means by which the perpetuation of this disease can be avoided. Seed selection for wilt control is effectively accomplished only in a seed plot. Experiments in Oregon have shown that a three-plant method of roguing is the most effective way of eliminating the wilt disease in seed tubers. The noticeably wilt-diseased plant and the next adjoining healthy-appearing plant on either side are removed. At least a 4-year crop rotation should be used.

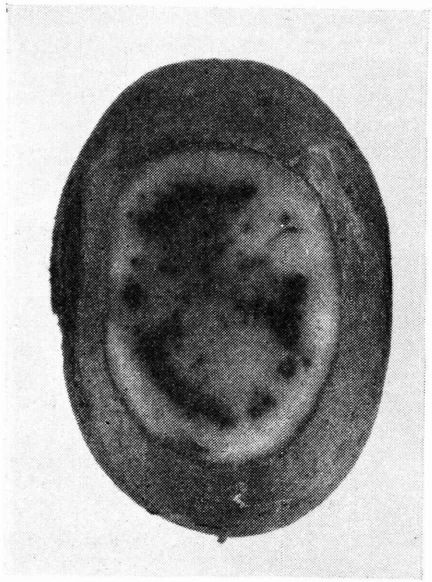

FIGURE 19.—Stem-end browning of tuber due to infection by *Fusarium eumartii*.

Stem-End Browning

Stem-end browning has been reported from Maine and some other States. Its cause or causes are unknown. It appears as dark brown or black streaks from ½ to 1 inch long, extending from the stem end (fig. 20) into the potato rather uniformly close to the skin, generally extending less than half an inch from the stem end of the tuber. It can be differentiated from stem-end browning caused by *Fusarium eumartii* in that the latter causes a discoloration of the vascular tissue, which is lacking in the nonparasitic stem-end browning.

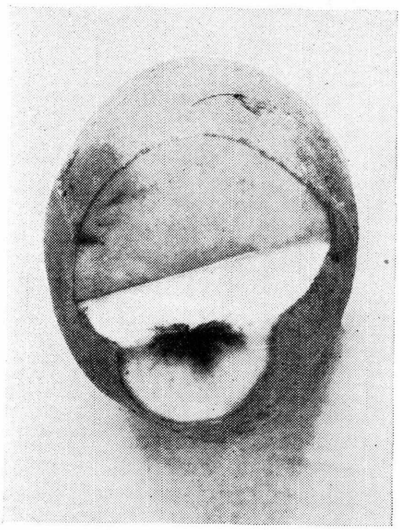

FIGURE 20.—Stem-end browning, cause unknown. A Green Mountain tuber with the stem end sliced off to show that typical stem-end browning does not extend deep.

Silver Scurf

Silver scurf (*Spondylocladium atrovirens* Harz) appears to be generally distributed over the United States. The affected portions of the skin often are smudgy or sooty when left undisturbed in storage, or they may take on a silvery appearance that is best seen when the tubers are wet. These spots may be large or small but generally are from ¼ to 1 inch in diameter and usually most abundant on the stem-end half of the tuber. The disease causes some loss in potatoes in storage by injuring the skin and permitting considerable loss of water, with consequent shriveling. Although

the table value of the potatoes is not impaired in mild cases, badly affected and shriveled tubers may become practically unsalable. The development of the disease in storage can be checked by keeping the tubers at low temperature and humidity. Although the disease cannot be entirely controlled, it is considerably reduced by seed treatment with mercuric chloride. Seriously affected tubers should not be planted, and long rotations should be followed.

Dry Rots

Dry rots (*Fusarium coeruleum* (Lib.) Sacc. and *F. trichothecioides* Wollenw.) are generally referred to as storage dry rots, and one form

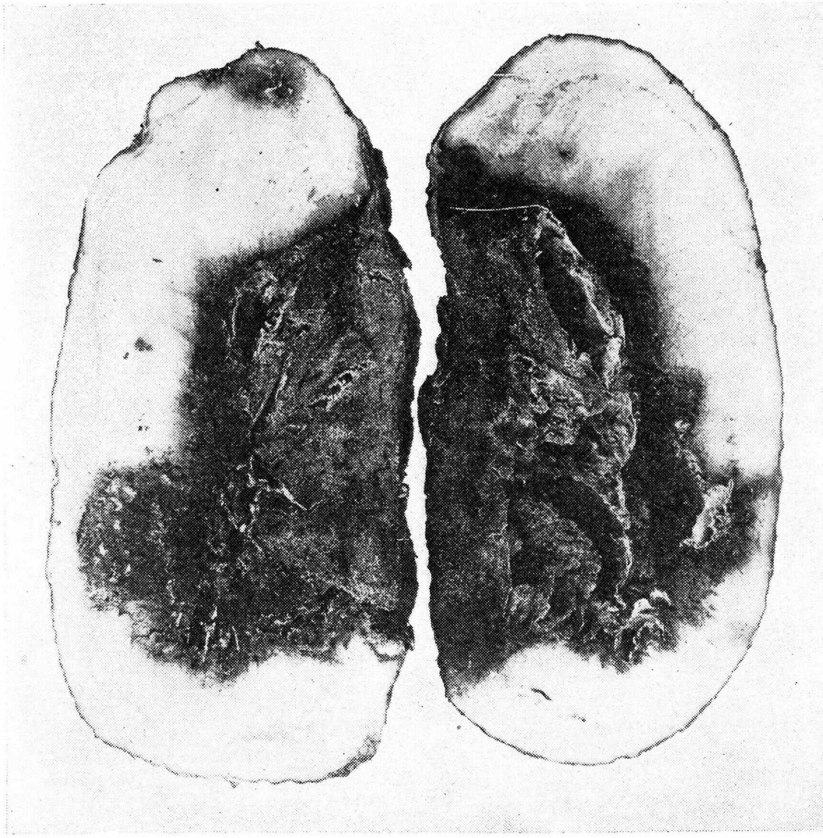

FIGURE 21.—Dry rot on potato caused by *Fusarium coeruleum*.

or another is likely to occur wherever potatoes are stored. The one caused by *F. coeruleum*, apparently the commonest, enters the potato generally through wounds and produces large sunken pockets or a wrinkled decay. Numerous bluish or whitish points or protuberances are formed on the surface of the decayed parts (fig. 21).

The powdery dry rot caused by *Fusarium trichothecioides* Wollenw. appears to be limited chiefly to climates having warm dry summers, and is prevailingly western in distribution. Affected tubers shrink

considerably and often develop in the interior large, hollow pockets partly filled with a brick-colored powdery mass of fungus growth. Pinkish or whitish tufts of fungus growth are occasionally produced freely on the surface of the sunken rotted areas (fig. 22). In storage the rot develops at a somewhat lower temperature than many of the other common rots.

In some types of fusarium dry rot the growing tuber may get the disease from the soil, the fungus probably entering through eyes, lenticels, or breaks in the tuber skin. In other types the fungus enters only through breaks in the skin. In view of the fact that these fungi occur so universally, it is practically impossible to get tubers that do not bear *Fusarium* contamination on their surfaces. As all of these fungi can enter most readily through wounds, fusarium dry rot is most frequently found in tubers that have been carelessly and roughly handled or injured by exposure to freezing temperatures.

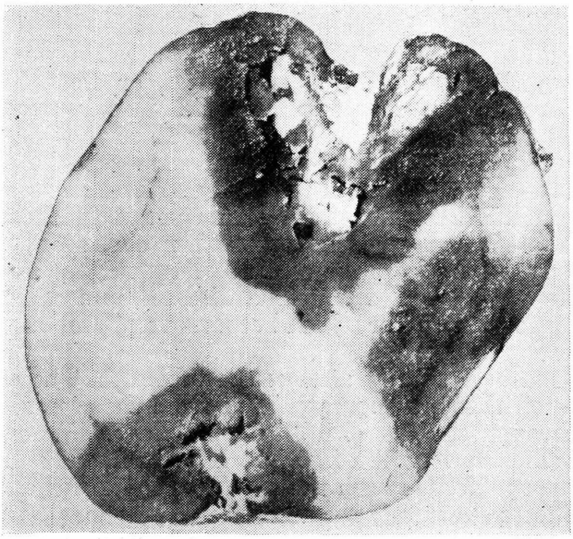

FIGURE 22.—A potato affected with powdery dry rot.

Even though these fungi are present on tubers they do not cause infection unless temperature and moisture conditions are favorable for the germination of the spores and growth of the causal fungi. Potatoes should be dug and handled throughout all storage and transit operations in such a manner as to cause a minimum of cuts and bruises. If the tubers have not fully ripened in the ground, they should not be handled after they are picked until sufficient time has elapsed for the skin to harden as well as dry; this is hastened by thorough ventilation.

Wound infection and the ensuing rot in storage cannot be prevented or controlled simply by manipulation of the humidity of the storage room. Prevention consists essentially in careful handling to reduce mechanical injury to the minimum. Control consists fundamentally in removing superficial moisture from the tubers as promptly as possible after digging, and keeping the stock dry during at least the

first 4 weeks of storage. It is desirable, however, to maintain a fairly high air humidity the first week after storage to insure suberization of bruised tubers. Special emphasis should be placed on the elimination of tuber wounds by improved harvesting operations.

Late Blight

Late blight (*Phytophthora infestans* (Mont.) DBy.) is one of the most destructive diseases in the New England and North Central States. At times it is also responsible for considerable loss in nearly all the Eastern Seaboard States, even as far south as Florida, and along the Pacific coast. It is not of great importance in the other Southern and in the Central States.

The disease is known as late blight because in most sections of the country it attacks the plants at or after the blossoming stage. In some places, however, including the coast region of the Pacific coast area and the northern Atlantic seaboard, the disease may appear early in some seasons, killing the plants as early as July. The disease may be noticed first as purplish or brownish-black areas on the blade of the leaflet or even the leafstalk, flower pedicel, or stem. Usually the lower leaves are the first to become affected. The diseased areas have a water-soaked zone about their margin, indicating the location of the advancing fungus. This recently invaded area becomes lighter colored than the normal green of the leaf, appearing as a light-colored halo about the blackened area, and in turn it blackens and dies. Under favorable warm and moist weather conditions, the disease spreads rapidly, with the result that all the plants in a field may be killed in a few days (fig. 23). The diseased and decaying tissues give off a characteristic odor which becomes very pronounced in fields that are severely attacked.

The organism also readily attacks the tubers that become infected either in the soil through spores washed from the diseased tops or in harvesting through contact with blighted foliage. When late blight tuber rot develops in the soil it is primarily brown, and spreads irregularly from the surface through the flesh like the diffusion of a brown stain. The affected part may become soft in consistency, partly because of an abundance of moisture but mainly because other organisms, particularly bacteria, follow the late blight fungus. Under storage conditions the disease is typically a dry rot, forming irregular sunken patches, which under conditions favorable for their development, such as high humidity and temperature, may involve the entire tuber. These patches are usually quite firm, unless secondarily affected by other parasites, and frequently they have a metallic tinge especially at the border of healthy tissues.

If late blight has been particularly prevalent in the field late in the season it is much better to delay digging the potatoes until 2 weeks after the potato tops are dead, preferably until after a frost has killed the vines. This delay is necessary to allow the numerous spores on the old dead plants and on the surface of the soil to die before the potatoes are dug. Without this 2 weeks' delay, a large number of the potatoes will become infected by the living spores with which they come in contact during the digging process. It is occasionally advisable, after a heavy attack, also to spray the old vines and the entire soil surface soon with a solution of copper sulfate at the rate of 10

pounds in 50 gallons of water in order to kill as many of the spores as possible.

Affected potatoes should not be used for seed because generally they either fail to sprout and so cause broken stands in fields, or give rise to diseased plants that act as centers of infection for the entire field. Even if clean seed is used the vines are not thereby protected against infection from diseased plants in neighboring fields.

Nearly all varieties of potatoes are susceptible to this disease, but the variety Sebago, recently developed by the United States Depart-

FIGURE 23.—Two rows of the variety Green Mountain killed by late blight. The plants in the two rows to the left are resistant to late blight and are still green.

ment of Agriculture, is very resistant and will produce a good crop without any spraying during years of moderate blight epidemics. Better results are obtained if during such years even this variety is sprayed, but the applications may be less frequent than in the case of susceptible varieties. Tuber rot due to late blight has very seldom been found in the Sebago variety even when the vines were attacked. The application of a copper fungicide to the vines during the growing season is the only real safeguard. A detailed account of methods of preparing and applying these fungicides is given on page 61.

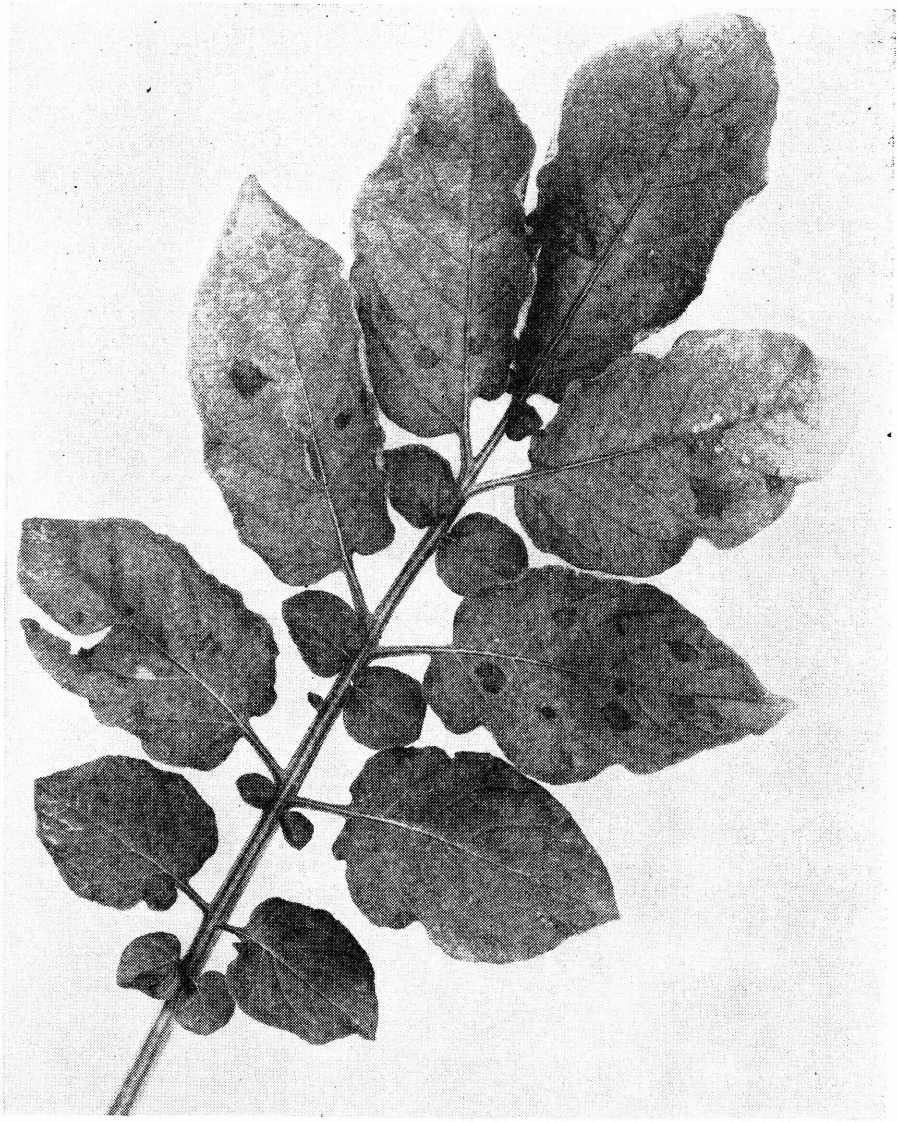

FIGURE 24.—Early blight lesions on potato leaf.

Early Blight

Early blight (*Alternaria solani* (Ell. and Martin) (Jones and Grout)) also known as leaf spot, occurs earlier in the season than late blight; it is also rather common late in the season when weather conditions are favorable for its development. It attacks the potato leaves, causing brown spots thereon, which as they enlarge develop concentric rings or markings, producing a target-board effect (fig. 24). When the spots are numerous they kill the leaves, and the yield of potatoes is consequently reduced.

Small, shallow, more or less circular decayed lesions are sometimes formed on the tuber. The margin of the diseased area is raised somewhat, and the immediately adjoining skin of the tuber is slightly puckered (fig. 25). The lesion may afford an entrance for saprophytic molds that complete the rotting of the tuber. This is especially true if seed potatoes are shipped to Florida or other southern points where the high temperature is favorable for the growth of decay organisms.

The disease can be successfully controlled by thorough and timely spraying with bordeaux mixture.

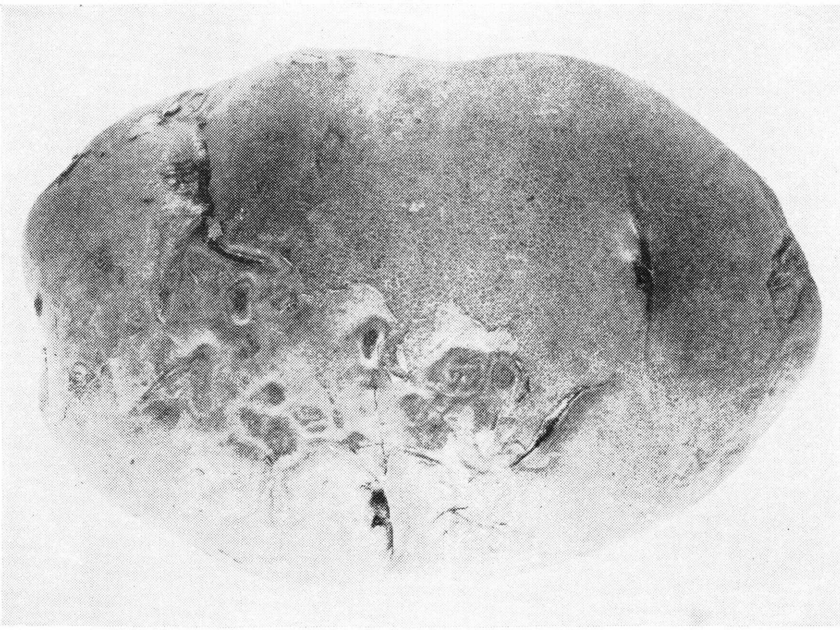

FIGURE 25.—Tuber spotting caused by *Alternaria solani*, Spaulding Rose variety. Note that the spots are limited to the skinned area. (By courtesy of the Maine Agricultural Experiment Station.)

Root Knot (Nematode Gall)

Root knot (nematode gall) (*Heterodera marioni* (Cornu) Goodey) is caused by nematodes or eelworms and has become a serious factor in potato culture in the West and to a certain extent in the South, not only through the direct injury to the potato crop but because infested potatoes are one of the most effective means of spreading the disease to the many other crops that are subject to it. The parasite invades the tubers and roots in many different places and produces swellings, or galls, varying in shape and size (fig. 26). The individual galls are more or less round, but they frequently run together, and then the tuber takes on a knotty and irregular appearance. When cut, such potatoes show a line of tiny glistening spots (the female nematodes) and slightly discolored watery areas just beneath the swelling. The root knot nematode attacks a large number of commonly culti-

vated plants, causing immense damage in some instances. Feeding roots, when seriously attacked by the nematodes, are unable to function properly, and the growth of the plant is checked.

Another species of nematode, *Tylenchus penetrans* Cobb, also attacks potatoes as well as many other crops. On potatoes the symptoms are as follows: The tuber is spotted in certain areas, or over its whole surface, by slightly elevated pustules. Sometimes these pustules run together. After the potatoes have been dug and have shrunken somewhat, the diseased areas may become surrounded by shallow channels, due to the collapse of the immediately adjacent tissues, and this shrinkage may be sufficient to cause the whole of a diseased area to present the appearance of a depression.

Both species of nematodes are able to spread in the soil to noninfested areas, but very slowly. However, they can be easily carried from field to field by running water or by soil clinging to agricultural implements, the hoofs of animals, and the feet of men.

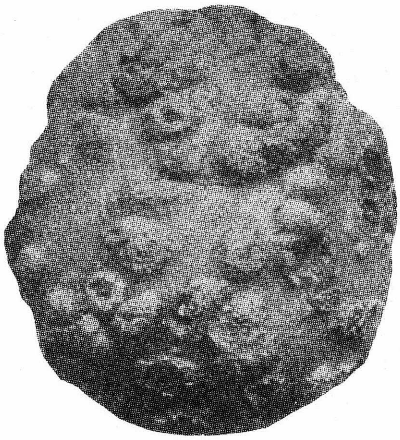

FIGURE 26.—A potato severely attacked by nematodes, showing the irregular knotted appearance of the outside of the tuber.

Where nematodes have become established in the soil they can be starved out by a 3-year rotation with nonsusceptible crops, provided weeds and volunteer plants of susceptible crops are rigidly excluded during this time. As an aid in accomplishing this, it is well to have at least some of the rotation crops planted in rows and thoroughly cultivated to insure complete absence of weed host plants. Clean fallow is most effective because the nematode is a parasite that cannot exist long without living host plants. Most of the nematodes die during the first and second years of clean fallow. Special care should be used to insure that the pest is not introduced into the field in seed potatoes. No potatoes from a field known to be infested should ever be used for seed; a mere inspection of the tubers will not reveal all cases of light infestation, and the introduction of the disease into the field might very readily be accomplished in this way. Detailed descriptions and recommendations for control are given in Farmers' Bulletin 1345, "Root-Knot: Its Cause and Control."

Tipburn and Hopperburn

Tipburn and hopperburn may be regarded as two distinct diseases. The symptoms, however, are very similar and consist of a gradual dying and blackening of the tip and margins of the leaflet, preceded by a slight yellowing of these parts. Half or more of the leaf surface may die. These affected margins roll upward, and all the dead tissue becomes very brittle so that it frequently is broken or torn (fig. 27). Plants affected with virus diseases, such as leaf roll or spindle tuber, are more susceptible than healthy plants.

Tipburn is caused by excessive loss of moisture from the leaves due to hot, dry weather. The withdrawal of water from the tissues may eventually cause the death of the leaves unless the condition is relieved by rainfall or by a reduction in temperature.

The potato leafhopper (*Empoasca fabae* (Harris)) has been shown to be a more usual cause of tipburn, but the effect is then known as hopperburn. This insect sucks the plant juice from the midrib or other veins, but the browning of the leaves results apparently from a toxic substance transmitted by the leafhopper. The development of symptoms is not dependent upon temperature and moisture conditions, but the severity of symptoms is increased by high temperature and lack of moisture.

Cultural practices that conserve soil moisture are helpful in reducing tipburn, and frequent applications of bordeaux mixture will help to control both tipburn and hopperburn. Pyrethrum powder and pyrethrum powder mixed with sulfur are effective as insecticides for this leafhopper.

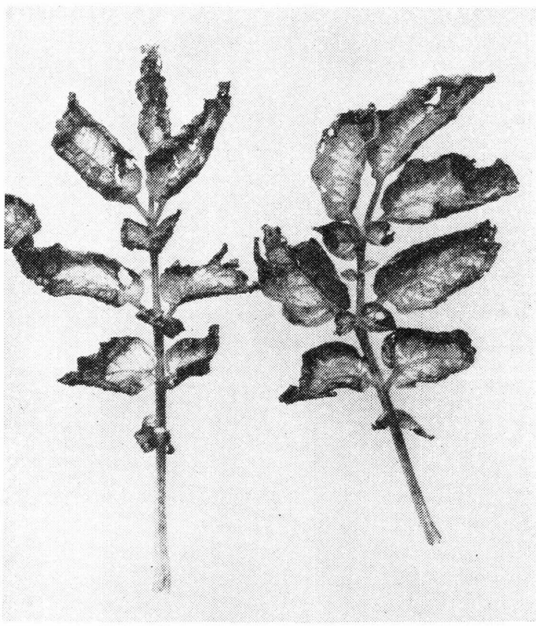

FIGURE 27.—Leaflets from a potato plant showing typical hopperburn symptoms.

Flea Beetle Injury

There are two species of flea beetles that attack the potato, namely, the potato flea beetle (*Epitrix cucumeris* (Harr.)) and the western potato flea beetle (*E. subcrinita* (Lec.)). The former is probably the more important of the two species for the country as a whole. The damage caused by the feeding of the adult beetles on the foliage is considerable, but the loss caused by the feeding of the larvae on the tubers is unquestionably of more importance. The larvae live in the soil and feed on the roots and developing tubers. The feeding of larvae on or near the surface of the tubers causes roughened pustulelike scars, whereas deeper feeding causes the formation of corky slivers about one-fourth inch long that extend into the potato at right angles to the surface. Tuber injury is further increased by scab infection in the wounds made by the larvae, which causes the scars to increase in size and depth.

Spray experiments conducted in Virginia against *Epitrix cucumeris* showed that the most effective control was obtained by spraying the plants with 4–6–50 bordeaux mixture to which 2 pounds of calcium arsenate had been added. The best results were obtained with this

material when it was applied six times at 7- to 10-day intervals throughout the growing season. Late spraying seemed to be more important than early spraying because the new brood of beetles, which appears about June 20 on the Eastern Shore of Virginia, is more abundant and injurious than the overwintering brood found in the field earlier in the season.

As the potato flea beetles feed on both surfaces of the leaves, care should be taken that the nozzles of the sprayer are adjusted so that the undersurface of the leaves will be thoroughly covered with the material used.

Spray experiments in the State of Washington also demonstrated that calcium arsenate added to bordeaux mixture was the most effective of the combination treatments, but complete control over tuber injury was never obtained.

It was definitely demonstrated in the State of Washington that the dates on which potatoes are planted have a direct bearing on the severity of the flea beetle injury to tubers. This is largely due to the life history of the insect, as there is only one complete generation and a partial second generation annually. In order to escape invasion of the new tubers by the larvae, it is recommended that early potatoes should be planted no later than April 19, and during March if possible. Late potatoes should be planted between June 15 and July 15. Potatoes planted in that interval developed tubers relatively free of tuber damage without the use of any insecticide. Protection of the tops may be obtained by spraying or dusting the plants with calcium arsenate-bordeaux mixture after they start to grow. In districts where potato flea beetles are troublesome no potatoes should be planted between April 19 and June 1. Similar results were obtained in Oregon.

VIRUS AND VIRUSLIKE DISEASES

A number of diseases of the potato not due, so far as known, to any living organism or to nutritional disturbances, have been receiving an increasing amount of attention from the standpoint of both the grower and the investigator. These maladies, formerly considered as degeneration diseases, are due to viruses. Until recently it was believed that because the potato had been propagated vegetatively for so many years, it had degenerated and was not able to continue to grow vigorously and produce large crops of tubers. The fallacy of this belief has been definitely demonstrated.

Plants infected with virus diseases will give rise to tubers, which, when planted, will produce plants that will develop the same disease. In this group fall such diseases as mild mosaic, rugose mosaic, leaf roll, spindle tuber, witches'-broom, yellow dwarf, and others.

The spread of potato virus diseases is frequently accomplished by sucking insects, especially aphids, that feed on a diseased plant and then on healthy ones. It is therefore not advisable to try to develop and maintain healthy stock by planting it adjacent to diseased lots. Some species of aphids are more effective carriers than others, and some virus diseases are more readily transmitted than others.

The prevention or reduction of the spread of virus diseases is accomplished mostly by early and thorough roguing in isolated seed plots, as described on pages 53–57.

Mild Mosaic

Mild mosaic can be recognized by a mottling in the green of the leaf, in which yellowish or light-colored areas alternate with the normal green, accompanied by a slight crinkling. These mottled areas are variable in size and are not limited by the veins of the leaf (fig. 28). Diseased plants droop and die prematurely.

Mosaic mottling is modified by climatic conditions. In the northern seed-growing localities it is usually more distinct during the early part of the season. When certain seasonal conditions, usually hot and more or less dry weather, continue during the entire growing season in these northern sections, mosaic mottling is very difficult to detect. Although under such unfavorable conditions mottling may not be apparent, it

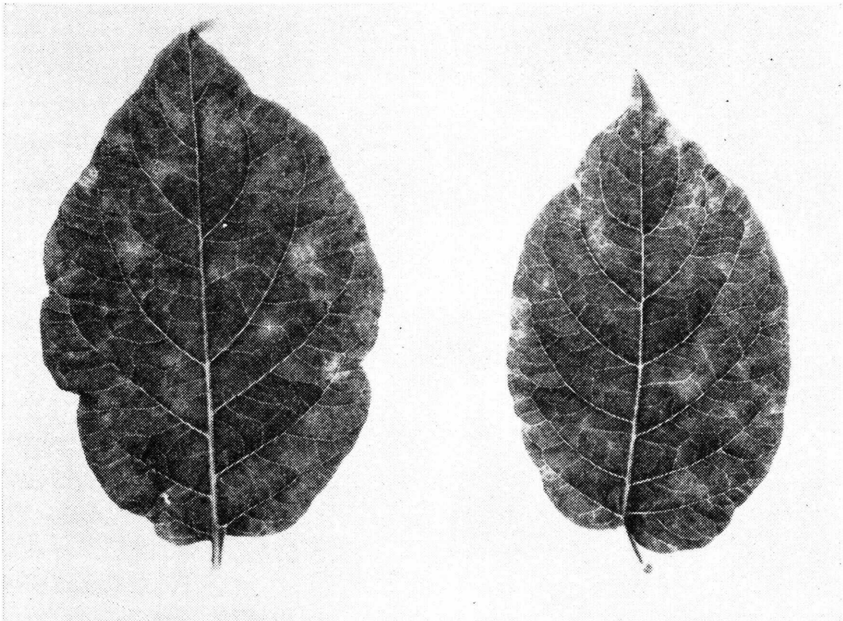

FIGURE 28.—Leaflets from a Green Mountain plant infected with mild mosaic. Notice how the yellow patches are interspersed with the normal green of the leaves.

does not follow that such plants are free from the disease. These plants or their progeny will show the mottled symptoms if again placed under conditions favorable for the development of mottling.

The only way in which mild mosaic can be avoided is in the selection of tubers from healthy plants for seed purposes. This is best accomplished in the isolated seed plot, where the seed pieces are planted in tuber units and any unit which shows the disease is removed. The United States Department of Agriculture has developed and recently introduced a number of varieties, namely, Katahdin, Chippewa, Houma, Sebago, and Earlaine, that do not contract the disease in the field. They are not absolutely immune, however, since the virus can be transmitted to them experimentally by grafting, but for practical purposes these varieties are as valuable as if they were immune.

Rugose Mosaic

Rugose mosaic is a more serious disease than mild mosaic and is entirely distinct from it. The mottled areas are smaller and more numerous and typically are distributed closer to the main veins. The mottling is readily masked under high-temperature conditions, but the crinkling of the leaves makes identification rather certain. The veins on the underside of the lower leaves often show necrotic areas as black, pencillike lines. Affected plants are considerably stunted and die much earlier than the healthy ones. Rugose mosaic is spread to other plants in the field by aphids. If infection takes place early in the season, current-season symptoms are apt to develop before the plant dies. If infection occurs late symptoms may not appear the same

FIGURE 29.—Current-season rugose mosaic symptoms due to spread of the virus from a diseased to a healthy potato plant. Tubers from this plant will produce typical rugose mosaic plants.

season, but tubers from such plants will carry the disease. Current-season symptoms are characterized by a burning and discoloration of the leaf veins and leaf blades, brittleness, leaf dropping, and premature death. At first these symptoms may appear only on a single shoot in a hill; later in the season other shoots in the same hill may show these symptoms (fig. 29).

The disease is subject to control by rigid roguing. Careful roguing even in mass-planted isolated seed plots can be depended upon to reduce the amount of disease in the seed stock, but tuber-unit roguing will give control and practical elimination of the disease much more easily and in a shorter time. The disease generally can be recognized by the time the plants are 2 to 3 inches high. To be effective, the roguing must be started early, and must be repeated often, preferably about

once a week in the early part of the season. Up to the present time no potato variety has been found resistant to this disease.

Leaf Roll

Leaf roll is characterized by the upward rolling of the leaflets lengthwise so that the midrib remains at the middle of the trough thus formed. Plants becoming infected with leaf roll while very young, or plants from tubers infected with leaf roll at first show rolling on the lower leaves, followed by rolling of progressively higher leaves until all leaves may be rolled later in the season. Plants infected late in their development may show rolling only in the upper leaves. Other symptoms of leaf roll disease (fig. 30) include dwarfing, rigidity, leathery texture, chlorosis, reddish or purplish discoloration of the affected leaves, and reduction in the number and size of the tubers. Net necrosis is a symptom of leaf roll of certain varieties that appears in newly infested tubers. It is a network of small brown strands of discolored tissue extending throughout the interior of the potato-tuber tissue at the stem end (fig. 31).

This disease is spread very rapidly by aphids. Roguing in isolated tuber-unit plots gives good control, but it has to be done rigidly and efficiently.

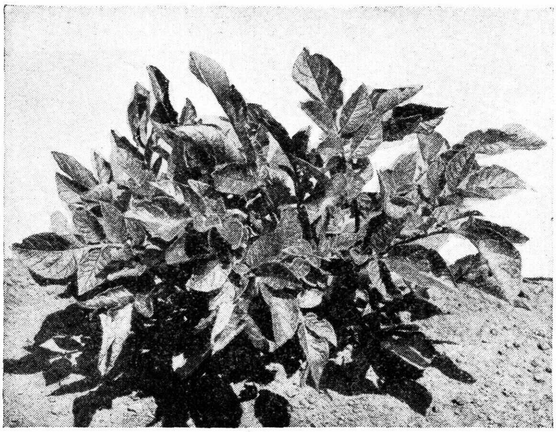

FIGURE 30.—Plant of Burbank variety affected with leaf roll disease. Rolling is particularly prominent in the lower leaves, though it is evident also in the upper ones. The foliage tends to be rigid and leathery, not soft and flexible as in normal plants. Diseased plants are noticeably stunted and lighter in color than the healthy ones.

Spindle Tuber

Spindle tuber is so named on account of the spindle-shaped tubers produced. Affected plants are characterized by slenderness and uprightness, and the foliage is a darker green than that of healthy plants. In Triumph, infected tubers are lighter red than the healthy ones and have a tendency to be blocky cylindrical in shape. Long tubers, especially, become spindling and pointed at the stem end (fig. 32). Shallowness of eyes and increase in their number is characteristic of this disease.

Experiments in Nebraska and Maine have shown that this disease can be transmitted by various insects including grasshoppers, flea beetles, tarnished plant bugs, and Colorado potato beetles. To some extent the disease may be spread by contact with cut seed pieces, by the seed-cutting knife, and by picker planters.

Because it is sometimes difficult to recognize spindle tuber in all affected individual plants in a mass plot, roguing in tuber-unit seed plots is particularly desirable for the control of this disease. As the disease is readily transmitted by the seed-cutting knife, it is desirable

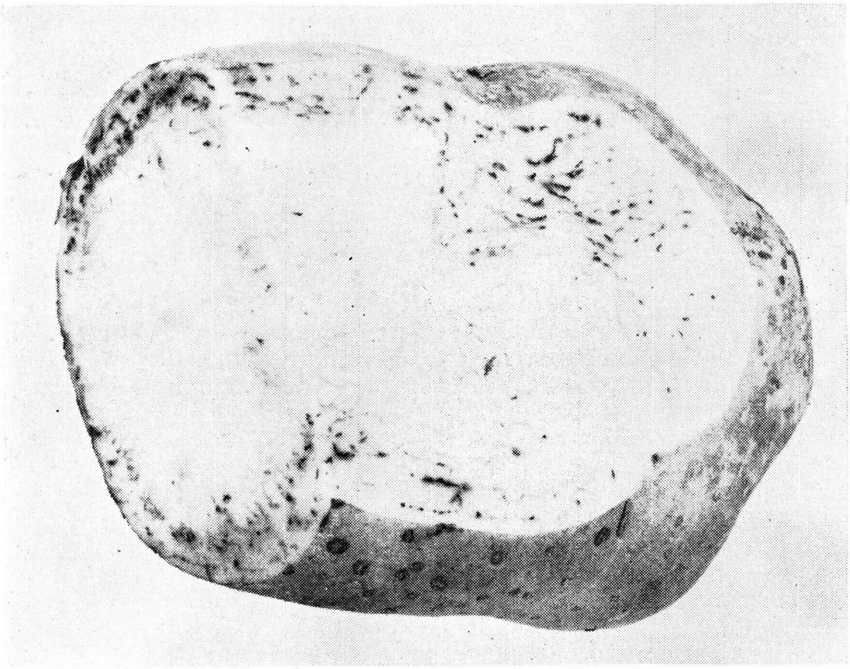

FIGURE 31.—Tuber with net necrosis, a transitory occasional symptom of leaf roll. (By courtesy of the Maine Agricultural Experiment Station.)

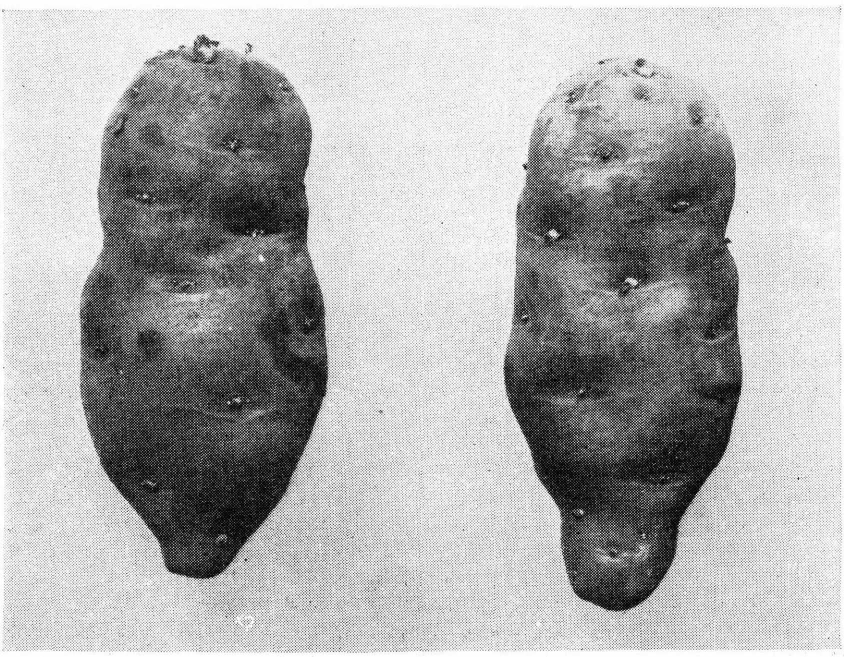

FIGURE 32.—Green Mountain tubers affected by the spindle-tuber disease. Affected tubers are elongated and more pointed at the stem ends than normal ones.

to disinfect the knife by dipping it in alcohol and flaming it after cutting each tuber and also to put each unit in a separate paper bag or other container. Use of bags can be avoided by not cutting all the way through the tuber. This keeps the seed pieces together, and they can be broken loose at planting.

Witches'-Broom

Witches'-broom seems to be confined primarily to some of the Northwestern States. Affected plants produce numerous slender, spindling sprouts none of which succeeds in producing a large plant or any appreciable yield. The leaves may be very small and somewhat velvety in appearance. Infected plants may not grow taller than 9

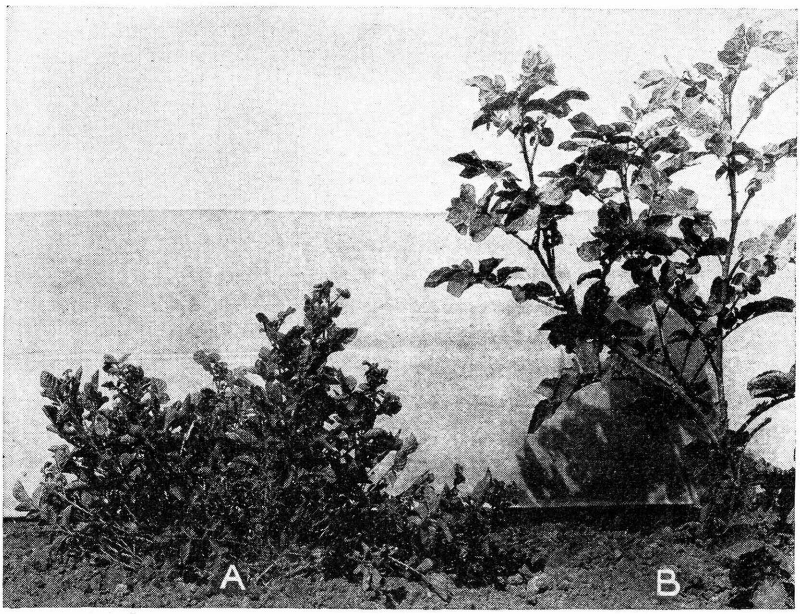

FIGURE 33.—Plants of the Triumph variety: *A*, Plant affected with witches'-broom disease; *B*, healthy plant. The affected plant is typical of the performance of badly diseased tubers.

inches (fig. 33), and they produce a large number of potatoes no larger than marbles. When affected tubers germinate they often produce numerous spindling sprouts. The way in which this disease spreads from plant to plant is not known. As it shows up in stock formerly healthy, it presumably is spread by some insect; however, all experimental work carried on to determine the identity of the insect has given negative results.

This disease can be controlled by roguing and by the selection of tubers from plants with strong normal sprouts.

Yellow Dwarf

Yellow dwarf has been reported from some of the Eastern and Middle Western States but as yet has not been found in the Pacific

FIGURE 34.—*A*, A healthy Irish Cobbler plant; *B*, the same plant which became infected early in the season with yellow dwarf. Most of the leaves show rugosity, upward roll of margins, and downward curve of the longitudinal axis. (By courtesy of the Wisconsin Agricultural Experiment Station.)

Northwest. The foliage of affected plants takes on a yellowish-green color, whereas the upper surface of the leaves becomes slightly rugose (fig. 34, *B*). Dying from the tip downward is characteristic, but under some conditions this symptom may be absent. High temperature and low humidity tend to hasten the death of infected plants. Brown spots in the pith of the stem are common. They appear shortly after yellowing of the foliage and may eventually extend the entire length of the main stem. In warm soil seed pieces from infected tubers often fail to germinate; others produce shoots that die before they reach the surface.

The effect of yellow dwarf on the tubers varies. Infected plants often produce small misshapen tubers, which in cross section show

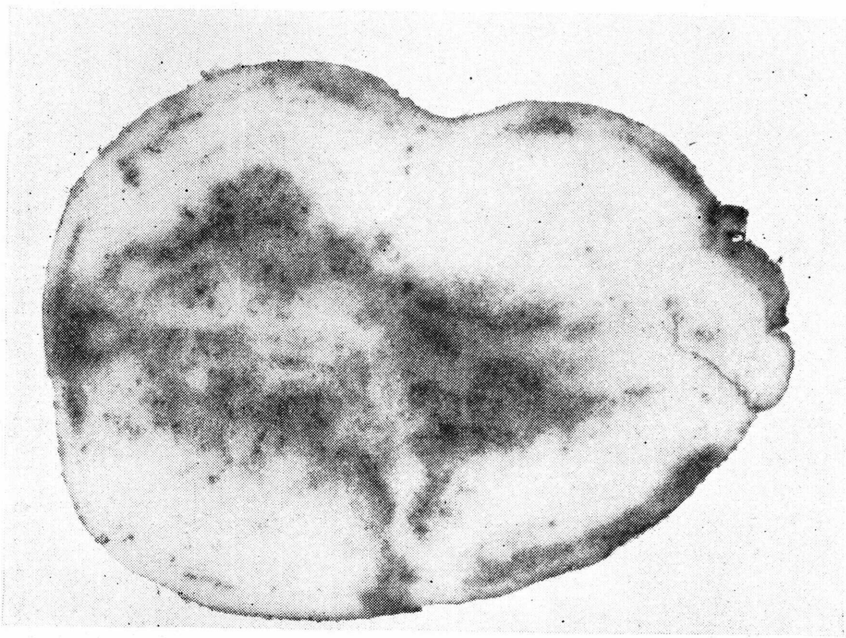

FIGURE 35.—Symptoms of yellow dwarf in potato tuber. Necrosis occurs in small areas throughout the pith and internal phloem. (By courtesy of the Wisconsin Agricultural Experiment Station.)

small necrotic areas scattered throughout the flesh (fig. 35). Growth cracks are common, but these are also characteristic of certain other diseases.

Experiments conducted in New York State have shown that this disease can be transmitted by the clover leafhopper *Agallia sanguinolenta* (Prov.). This insect retains the virus during the winter and infects healthy plants in the spring.

No control measure is known except the planting of disease-free seed. As the clover leafhopper transmits the disease, it may be desirable to plant potatoes some distance from clover fields.

Haywire

Haywire has been found in a number of States, and although generally it is not important the affected plants are very noticeable. This disease is believed to be of virus origin because apparently it has been transmitted to healthy potato plants by the inarch method of grafting. According to reports such abnormal plants have been observed for at least 15 years in Nebraska, but until the last 4 or 5 years they have not occurred in numbers large enough to cause any great concern. The disease is characterized by late emergence on missing hills, and sometimes the dormant seed pieces produce sprout tubers. The plants are severely dwarfed (fig. 36) and have a rosette appearance due to a cessation of the terminal growth, a shortening of the internodes, and

FIGURE 36.—Haywire on Bliss Triumph potato plants. Notice the severe dwarfing and rosette appearance. (By courtesy of the Nebraska Agricultural Experiment Station.)

an increase in the number and development of axillary shoots. The leaflets are usually rugose, erect, stiff, rolled, pointed, and slightly yellowish and often have a purple coloration at the tips and margins. Petioles and stems may show swellings at the nodes with a red or purple pigmentation. Sometimes aerial tubers are formed in the leaf axils. Tubers are few or lacking and are set close to the stem.

Although no definite evidence is available, it appears that the disease is possibly transmitted by some insect. Infected plants should be removed from the field.

Calico

Calico is a disease characterized by the occurrence of large irregular yellow to cream-colored spots on the leaves. In some cases as much

as 70 percent of the leaf surface may be entirely lacking in chlorophyll; then again only occasional leaves may show a few spots. Generally, however, the spots are numerous and are well distributed over the plant.

FIGURE 37.—Irish Cobbler variety. *A*, Plants exhibiting pyramidal shape characteristic of psyllid yellows and secondary growths of curled leaves at tips of branches. As shown, the older leaves roll upward, assume radical positions, and finally die, leaving only the secondary leaves attached to the primary stems. *B*.—*a*, Plant affected with psyllid yellows; *b*, healthy plant. Leaf rolling is pronounced, and there are aerial tubers in the axils of the leaves. The disease was produced by placing 50 nymphs of *Paratrioza cockerelli* on a plant under a celluloid cage.

It appears to be systemic, as generally all the tubers from an infected hill will give rise to the same condition if used for seed.

The trouble can be controlled by roguing affected plants during the growing season.

Psyllid Yellows

Psyllid yellows is induced by some toxic substance injected into the plant during the feeding of the nymph of an insect known as the potato or tomato psyllid *Paratrioza cockerelli* (Sulc.).

Although not due to a virus, this disease is systemic in nature and results in a complete upsetting of the form and physiology of the entire plant. It is known to occur in the Western States and is especially serious in some parts of Colorado, Utah, and New Mexico. During certain years it has caused severe damage in Nebraska, Wyoming, and Montana.

The first symptoms consist of a marginal yellowing and an upward rolling of the basal portion of the smaller leaflets on the young leaves of infected plants. Under field conditions, and especially when diseased plants are exposed to intense sunlight, the basal rolling or cup-

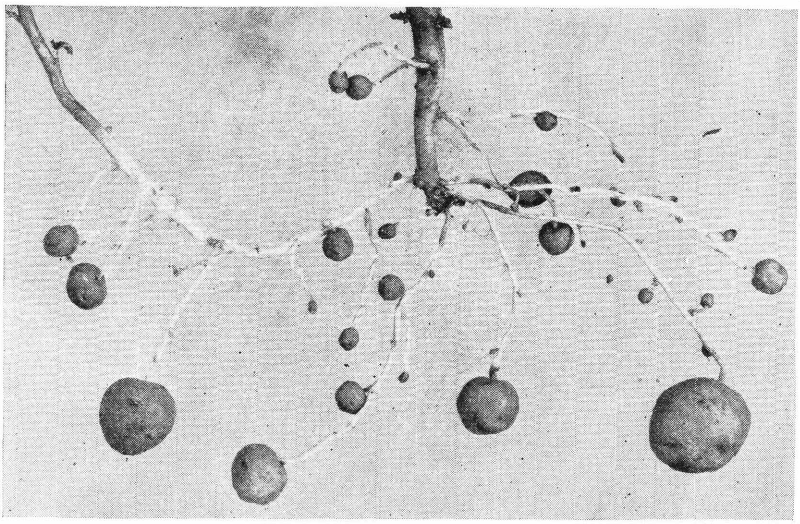

FIGURE 38.—Underground portion of a Triumph plant affected with psyllid yellows. One stolon has developed directly into a new shoot. Others have given rise to secondary stolons or tubers at their nodes. A diseased plant of this type may produce from 50 to 150 tubers. At the time it was dug, this plant had 46 tubers already set.

ping of the young leaves in all varieties observed becomes very pronounced. The rolled portions, and frequently other portions of the leaf, assume a distinctly reddish or purplish color. The older leaves of the diseased plant roll upward over the midrib and become yellow. Brown necrotic areas develop, bringing about the early death of the entire leaf. Buds above and below the ground are stimulated into activity. Above ground the axillary buds may develop into stocky shoots that frequently branch and, when fully developed, give the plant a compact and pyramidal shape (fig. 37). In some cases the axillary buds develop into aerial tubers along the entire stem, or produce short leafy shoots with rosettes of small leaves which, in advanced stages of the disease, may become bright yellow. Several tubers may develop along a single stolon and numerous small potatoes result (fig. 38). Of all the diseases of the potato this one is most disastrous

and often results in complete crop failure. If the plants are attacked when young, no crop is produced.

Spraying potato plants with lime-sulfur–zinc arsenite has given excellent results in controlling psyllids as well as flea beetles. The formula consists of $1\frac{1}{4}$ gallons liquid lime-sulfur (32° Baume), $2\frac{1}{2}$ pounds of zinc arsenite, and 50 gallons of water. The solution is applied at 350 pounds pressure with three nozzles to the row. It is advisable to stagger the lower nozzles to get a tipping and swirling action, which gives better coverage of the lower leaves. Growers are advised to make two or more applications. The first application is made when the plants are 6 to 8 inches high; the others follow at intervals of 10 days to 2 weeks.

The disease is not carried over in the tuber, but there is a general weakening of plants grown from infected tubers.

Purple-Top Wilt

During the more advanced stages of purple-top wilt the symptoms resemble those of psyllid yellows. This disease has been especially noted in Minnesota, and apparently the same condition, but known as blue stem, has been found in West Virginia, Pennsylvania, and Maryland. It probably is also the same as that known in Michigan as the moron disease. The first symptoms appear at the apex of the plant. The young leaves fail to enlarge normally, and the leaflets roll upward. The most pronounced rolling is at the base of the leaflet. In varieties with red pigment the coloration is accentuated, the reddish-purple color being most intense at the base of the leaflet, where the curling is most evident. Pigmentation is usually accentuated also on the stems of diseased plants, being especially pronounced in the Rural variety.

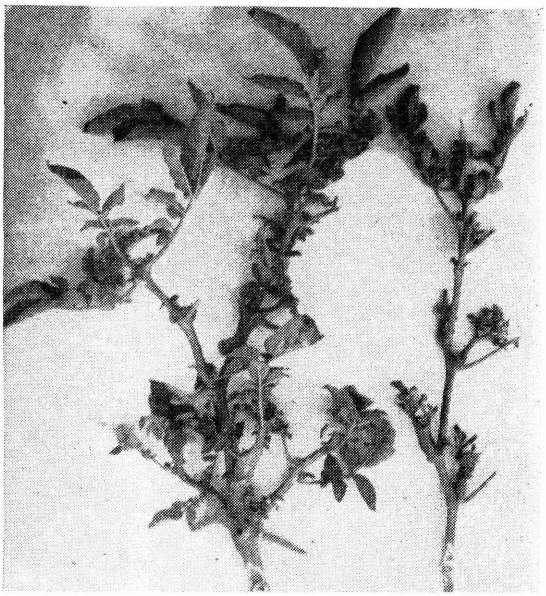

FIGURE 39.—Symptoms of purple-top wilt on two shoots of the Chippewa variety. Some of the leaves have been removed to show swollen stems of axillary shoots. (By courtesy of the West Virginia Agricultural Experiment Station.)

In varieties lacking pigment the topmost leaves become chlorotic, assuming a light green or yellow cast. An abnormal number of axillary shoots develop but soon show the above-mentioned symptoms. The axillary shoots become swollen at the base, often forming distinct aerial tubers (fig. 39). The vascular tissue of the stem turns brown at the time the foliage symptoms appear. The brown bundles may extend only a few inches above ground, but usually extend well into the

stolons. Necrotic flecks are often present in the pith of the lower part of the stem. The plant generally wilts within 2 weeks after the symptoms appear, and death of the plant may soon occur. Plants affected in late summer may mature late, and when these are killed by frost the stems turn intensely black. An internal necrosis of tubers extending from the stem end is characteristic of the disease on Rurals in West Virginia but may be absent on other varieties and on Rurals in other regions. Occasionally tubers from infected plants are flabby. According to experiments conducted in Minnesota, there is some evidence that this disease is due to the same virus as aster yellows, and that the virus is carried by the leafhopper *Macrosteles divisus* (Uhl.). Purple-top wilt is not transmitted as such through the tubers, but the tuber progeny of plants affected with the disease are much less vigorous than the progeny of healthy plants.

No control for this disease is known.

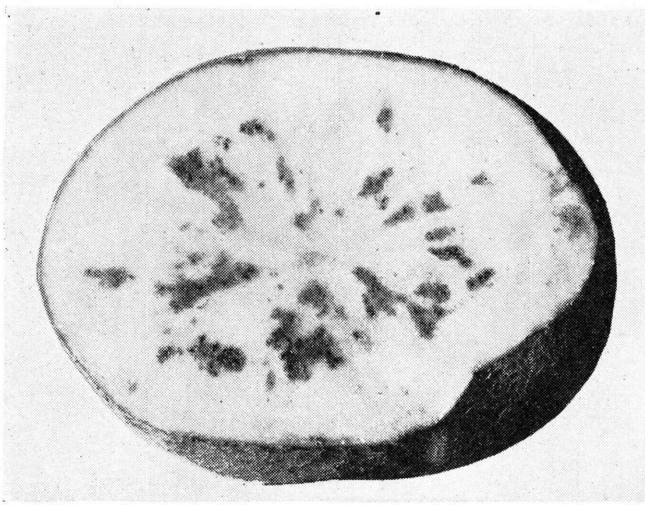

FIGURE 40.—Internal brown spot on potato.

DISEASES DUE TO NONPARASITIC CAUSES

In this group are included diseases that seem to be due to unfavorable environmental conditions and are not known to be caused by any virus fungus or bacterium.

Internal Brown Spot

Internal brown spot is characterized by irregular, dry, brown spots or blotches scattered through the flesh of the potato and not restricted to the water vessels (fig. 40), as is the case in the vascular diseases. These brown spots consist of groups of dead cells free from bacteria and fungi. No definite foliage trouble is associated with this disease.

Recent experiments in Germany have demonstrated that there is a close relationship between this trouble and the lack of available soil moisture during the latter part of the growing season and that it is more injurious on some varieties than on others.

No measures have been worked out that will prevent the occurrence of internal brown spot in the field. Favorable cultural conditions may at least reduce the severity of this disease. Affected potatoes should not be used for seed because they may give rise to weak plants.

Heat and Drought Necrosis

Heat and drought necrosis has been noted in tubers grown in light soils in the hot arid potato sections of the United States. It has been noted especially in the early crop grown in the volcanic ash soils of Idaho and seems to occur in tubers that are allowed to lie in the hot soil after the vines begin to die. It is marked by a golden-yellow to brown discoloration of the water vessels of affected tubers, this being most pronounced in the ring tissues, either at the stem end or bud end, and in the tissues between the ring and the tuber surface. Discoloration at first is restricted to the vascular tissue, but after a time it spreads slightly to surrounding tissues, and the color changes from golden yellow to a light or dark brown. The affected tissues die. Upon cutting it is found that the discolorations are not due to a solid dark mass of tissue but to discolored strands which impart a dark hue to the tissue just above them.

Control involves keeping the soil moist, cool, and shaded and in digging the tubers as soon as the vines begin to die if the soil is light and the weather hot.

Frost or Freezing Necrosis

If exposure of potatoes to freezing temperatures leads to ice formation in the tissues, it may cause a variety of symptoms known as freezing injury. Sometimes these symptoms are general and readily apparent externally; at other times they are localized internally and are visible only upon cutting. The latter type is known as frost or freezing necrosis, whereas the former is known as freezing. Both types of symptoms can be detected only after thawing.

Tissues killed by freezing are very wet and usually become infected with bacteria which cause a foul-smelling slimy or sticky rot if the tissues thaw in a warm, humid atmosphere; or the tissues may dry down to a mealy or tough leathery granular chalky mass if they thaw in cold or dry air. If only one side of a tuber is frozen, the killed portion frequently is sharply set off from the unaffected area by a purplish or brown line of corky tissue. Often fusarium tuber rot sets in before the unaffected cells are cut off by the corky layer.

Generally, however, freezing necrosis is marked by internal discoloration, of which there are several types. One, the ring type, is limited to the vascular ring and immediately adjoining tissues. Another, the net type, is marked by more or less blackening of the vascular tissue and the fine strands that extend from the vascular tissue into the interior pith and outer tissues (fig. 41). Finally, there is a blotchy type, marked by irregular patches ranging in color from an opaque gray or blue to sooty black, which may occur everywhere in the tuber. When these blotches are in the outer tissues they may be apparent externally in clear tubers with white skins. This is the only type of freezing necrosis that may be visible externally. Tubers affected with any or all of these types of freezing necrosis generally shrivel or

wilt more than nonaffected tubers. However, excessive shriveling alone cannot be relied upon as a sign of freezing necrosis.

If tubers are exposed to temperatures that are low but not low enough to cause ice formation, sugars increase, and the tubers become sweet. This sweetness disappears if these tubers are kept at temperatures above 40° F. Frozen tissues, however, are no sweeter than uninjured ones; therefore, sweetness of tubers is not a sign of freezing injury. Potato tubers will not freeze at 32°. The critical temperature, that is, the temperature at which ice begins to form, lies between 29.5° and 26.6°. It is impossible to forecast the critical temperature for a particular tuber because there are differences in the individual susceptibility to freezing. The length of exposure to freezing temperatures is also an important factor. It is not advisable to plant tubers showing severe freezing necrosis, as tubers that have been severely affected usually rot in the soil before sprouting. Potatoes showing only slight freezing necrosis may ultimately produce normal plants, but in general they should not be planted if sound seed stock can be obtained. To prevent freezing injury, tubers should not be exposed to temperatures below 32°.

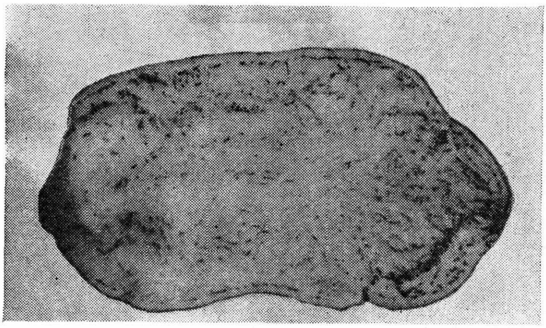

FIGURE 41.—Frost or freezing necrosis.

Sunburn and Sunscald

Sunburn and sunscald are caused by the exposure of tubers to the sun during growth or after digging, either in the field or in transit or storage.

Sunburn, or greening, results from exposure to light and does not involve the killing of the affected tissues. It frequently occurs in growing tubers. It is accompanied by a pungent taste and renders tubers unpalatable for most people and even poisonous for a few. In cases of long exposure the outer tissues turn deep green and those underlying, a greenish yellow or a deep yellow. If dug before maturity, tubers turn green or yellow and shrivel more readily than mature ones with well-developed cork layers.

Frequently the exposure to sunlight and resulting high temperatures lead to the killing of the cells. This is known as sunscald. Often the affected tubers become watery and turn brown throughout, or at least to a considerable depth. In other cases, freshly scalded areas have a blisterlike appearance externally and a metallic color, the underlying tissues being quite watery. Such areas may dry out and appear chalky and granular or hard and leathery. Most frequently, however, they are attacked by bacteria that cause foul-smelling bacterial rots or by the fungus that causes leak.

The only possible control of sunburn and sunscald is to prevent the exposure of tubers to the sun for prolonged periods of time.

Spindling Sprout (Hair Sprout)

Spindling sprout or hair sprout is characterized by abnormally slender and feeble sprouts (fig. 42). It indicates a constitutional weakness of the tuber which may or may not be associated with the presence of other specific diseases.

When the disease is a nontransmissible form, some of the sprouts have a diameter about one-half to one-fourth that of normal plants, and when the seed pieces bearing them are planted the resulting plants develop small tubers weighing an ounce or less. Experiments carried out in Maine show that when these small tubers are planted they form stocky, vigorous shoots and develop normal tubers weigh-

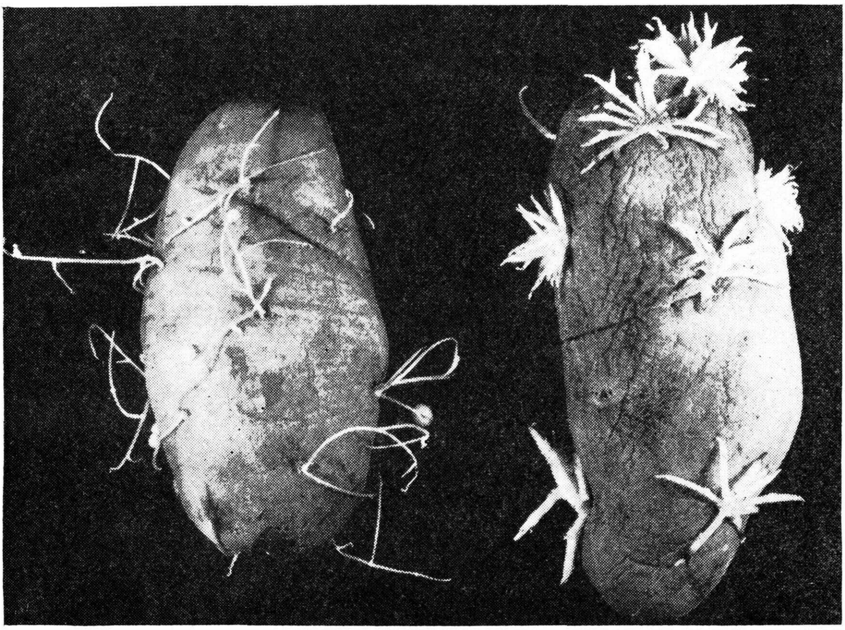

FIGURE 42.—Spindling sprout on White Rose and healthy control tuber, kept in storage for 12 months.

ing from 5 to 7 ounces. When healthy tubers were grafted with plugs from spindling sprout tubers they did not transmit spindling sprout. A spindling sprout similar in appearance may be due to witches'-broom or leaf roll, and should not be confused with the nontransmissible type of spindling sprout.

Presprouting has been recommended as a method to determine whether or not spindling sprout is present in seed lots coming from areas where this trouble has been prevalent in the past.

Blackheart

Blackheart is a result of asphyxiation of the tissues of the potato tuber. It occurs either when the temperature is too high, or when ventilation is so poor that the supply of oxygen is inadequate, or under various combinations of such conditions.

The symptoms of blackheart vary, depending upon whether the uninjured tubers were exposed to high temperature and a normal air supply, or to high, low, or normal temperatures with an insufficient air supply. Asphyxiated tissues are easily invaded by bacteria and fungi. These cause various forms of watery or slimy decay which soon hide the typical blackheart symptoms.

The external symptoms of blackheart are moist areas on the surface, which may be purplish at first but turn brown or black within a short time. The internal symptoms are a dark-grayish to purplish or inky-black discoloration (fig. 43). Tissues cut soon after the injury are of normal color; shortly after access to the air, however, they turn pink, then gray or purplish, and finally jet black. Sometimes all colors, save the pink, are found simultaneously in the same tuber; at other times only gray or brown colors are found, which is the case when tubers are heated above 130° F. or when they are deprived of all oxygen for considerable periods after death, as in waterlogged soils or in flooded storage pits.

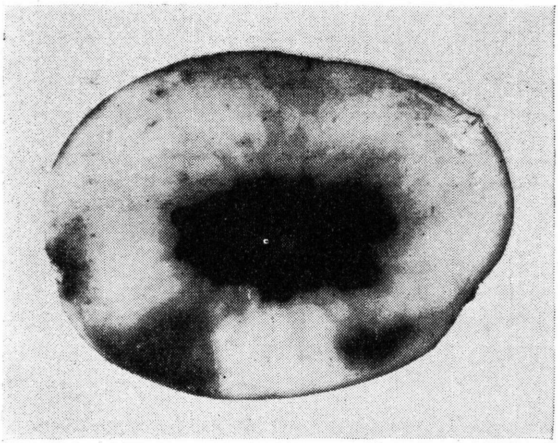

FIGURE 43.—A potato showing blackheart.

The discolored areas usually are sharply set off from the healthy tissues. Generally, the discoloration is restricted to the heart of the tuber, but frequently it radiates to the exterior as well. The discolored regions may appear in zones in the outer parts of the tuber and be absent or less evident in the center. The affected tissues are firm and even leathery if they have dried a little, quite unlike those affected with leak, which frequently show colors similar to those of blackheart. In advanced stages the affected tissues dry out and cavities result.

As tubers will not develop blackheart at temperatures below 95° F. if given a good supply of air, control involves avoidance of high storage temperatures and provision for good ventilation. The temperatures in heated cars should not be allowed to go above 60° or 70°. To prevent a shortage of oxygen, tubers should not be stored in solid piles more than 6 feet deep, even at low temperatures. They should not be left long in hot, light soils after the vines are dead nor be left lying on the surface after digging during hot weather.

Hollow Heart

Hollow heart consists of a more or less irregular cavity in the center of the tuber, usually without any discoloration of the surrounding tissues, though occasionally the adjacent cells assume a brownish

corky appearance (fig. 44). This abnormal condition is confined commonly to the large tubers and occurs mainly in seasons or under conditions favorable for rapid growth. It is not a decay and has no effect on the succeeding crop, though affected stock is undesirable for eating.

On soils where the trouble is apt to appear, it can be very largely, if not entirely, avoided by closer spacing of the plants, which will prevent such rapid and uneven growth of the tubers and the tendency of the tubers to split internally.

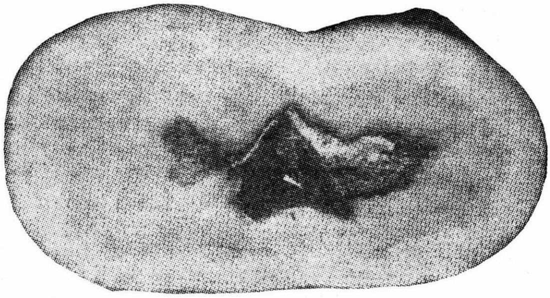

FIGURE 44.—A potato showing hollow heart.

Enlarged Lenticels

Enlarged lenticels occur when potato tubers are left for some time in very wet soil or are stored in a very moist atmosphere after digging. A large number of scablike openings appear in the skin as if pushed out from below and frequently assume a corky appearance later (fig. 45). This condition is merely the result of an excessive development of the natural pores or lenticels, which ordinarily appear as inconspicuous slits on the surface of the tuber. No damage is done except from the standpoint of appearance.

FIGURE 45.—A potato with abnormally enlarged lenticels.

Second Growth (Knobby Tubers)

Second growth or knobby tubers may be caused by such diseases as giant hill and yellow dwarf. Some varieties, especially those having long tubers, are more inclined to knobbiness than others. This condition often develops as a result of dry weather prevailing during midseason and followed by a rainy spell. Under such conditions tuber growth temporarily ceases during dry weather and is resumed after a rain. This causes an abnormal growth response, resulting in knobs at various parts of the tuber (fig. 46). This trouble may also occur as a result of irregular irrigation.

Proper farm practices and the turning under of sufficient humus to retain the moisture is recommended to avoid this abnormality.

Secondary Tuber Formation (Sprout Tubers)

Occasionally seed pieces are found that develop small new tubers without the formation of sprouts; or if they are formed, they extend

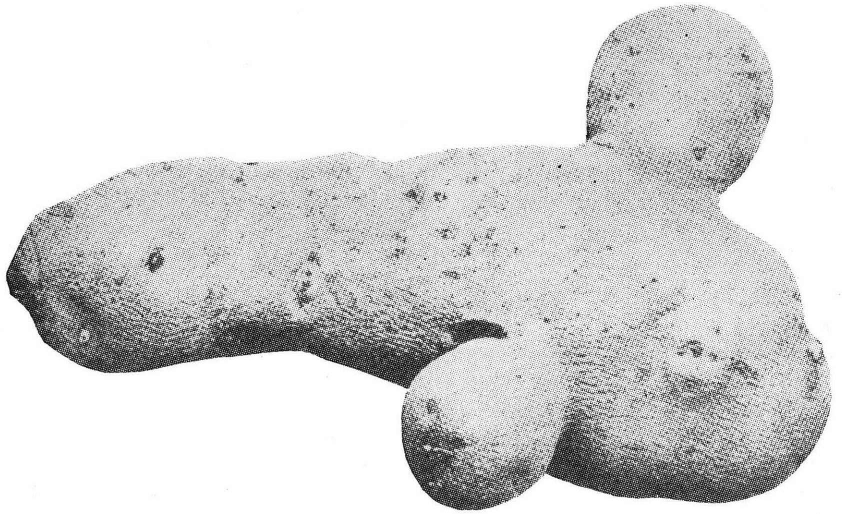

FIGURE 46.—A potato showing second growth; pointed end and knobs.

from the new tubers (fig. 47). This condition is known as secondary tuber formation or sprout tubers and takes place only when the rest period has been completed in the spring after the seed is planted,

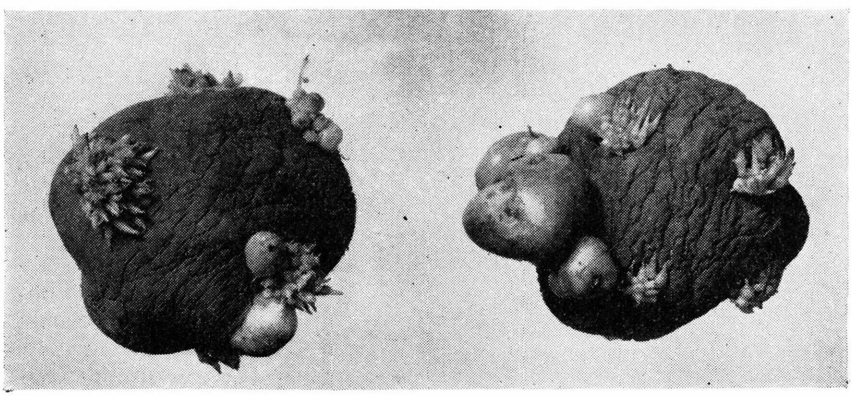

FIGURE 47.—Potatoes with secondary sprout tuber formation. Also known as "potatoes with no tops."

or during the prevalence of conditions unfavorable to normal vegetable growth. The first indication of this trouble in the field is a poor stand. When such seed pieces are examined they are found to be firm, but a small potato about the size of a marble has grown

directly from an eye or a short sprout. It is believed that this abnormality is caused by an excessive concentration of the cell sap of the tubers. Storage that favors early sprouting or unusually long storage in light at a fairly warm temperature, 65° to 68° F., predisposes the potato to form secondary tubers.

The most important factors in avoiding sprout tubers are cool storage and late planting.

GENERAL CONTROL MEASURES

CROP ROTATION

As a number of disease-producing organisms live over in the soil or on tubers left in the soil after digging, it is advisable to rotate potatoes with nonsusceptible crops so as to eliminate or reduce the potato-infecting organism by starvation. This method is especially applicable to such diseases as rhizoctonia canker, scab, fusarium wilt, verticillium wilt, and root knot. It is known that some of the organisms producing disease in potatoes can remain alive in the soil for more than 3 years. Whenever it can be arranged, it is best to grow potatoes on the same land not oftener than once every 4 to 5 years, and in the meantime to plant crops not affected by potato parasites.

SEED SELECTION

The chief improvement to be made in seed-potato stocks by selection methods is through the prompt elimination of seed tubers infected with viruses and wilt-producing organisms and of diseased and weak plants in the field. Four methods of improvement or a combination of some of these may be used in obtaining commercially desirable seed potatoes: (1) The tuber-indexing method; (2) the tuber-unit method; (3) hill selection; and (4) mass roguing.

Tuber-Indexing Method

The tuber-indexing method is the most recently devised and the most effective method of eliminating diseased potato tubers from seed stock intended for planting in the seed plot. It involves the numbering of all seed tubers and the growing of one eye from each tuber well in advance of field planting to determine whether the tuber is healthy. Generally, the indexes are grown in pots in the greenhouse (figs. 48, 49). All tubers detected in this way as being diseased are discarded, and only the remaining healthy ones are kept for planting in the seed plot. Where facilities are available for doing the work effectively, this is undoubtedly the most nearly ideal method now known for controlling the potato virus diseases. However, this method is not well suited for the elimination of spindle tuber, as this disease is rather difficult to detect in a lot of indexes.

The best method of handling the mother tubers from which the index sets have been removed is to hold them for 10 days to 2 weeks in moist air at a temperature of 60° to 75° F., after which they may be held at 40° to 45° until planting time. The higher temperature with relative high humidity favors thorough healing of the cut surfaces.

In the North, tuber indexing is necessarily limited to the greenhouse. Where a fall or second crop is grown, as in southern New Jersey, on the Eastern Shore of Maryland, in Virginia, and in practically all of the Southern States, it is possible to practice the tuber-indexing method with the spring crop by planting the set from the numbered tuber in the open field and properly labeling it. Observations can be made during the growing season in ample time for a second-crop planting of indexed tubers that are apparently free from disease. By doing such work in the far South, it is possible to grow the indexed set to maturity before the normal planting time in the North. Certain State and private seed-certification agencies are now resorting to this practice in order to get a "reading" on the behavior of their certified seed potatoes. At the usual

FIGURE 48.—Tuber indexes of potatoes growing in a greenhouse. Each pot contains a plant grown from one eye of a tuber. The number on the label in each pot corresponds to the number of the tuber from which the eye was taken. In the event the indexed plant shows infection with a virus, the corresponding tuber is discarded. The tubers indexed as healthy are planted in an isolated plot in tuber units to facilitate roguing.

planting time the tubers found to be free from disease are planted in a seed plot as tuber units in the manner described hereafter. It is then easy to identify in the growing plants any disease from an infected tuber that may have escaped the observer of the tuber-index set. From this point in the process the practices are the same as those outlined under the tuber-unit method.

Tuber-Unit Method

The standard tuber-unit method involves selecting from the seed bin before planting time well-shaped tubers ranging from 6 to 8 ounces in weight. Planting the seed plot in tuber units of four, that is, planting all the seed pieces cut from a single tuber one after another in the

row, enables the grower to recognize diseased plants more readily and permits roguing to be done more accurately and earlier than is possible with other methods. This gives conditions that are the most favorable for the control of virus diseases by field-plot methods. By leaving additional space between sets of fours, the units are definitely isolated, and the grower can readily observe the presence of diseases and compare variation in vigor and uniformity among the various units. It is easier to detect disease when the seed pieces from each tuber are thus grouped together, and late-growing seed pieces can be removed before they are up, if the more advanced sister hills in the same tuber unit show symptoms. Experiments have shown that the tuber-unit method of roguing is much more effective than mass roguing.

To facilitate tuber-unit planting, growers in some States have made use of a two-man planter. The seed tubers are cut individually, and the sets from each tuber are placed in a suitable-sized can with the

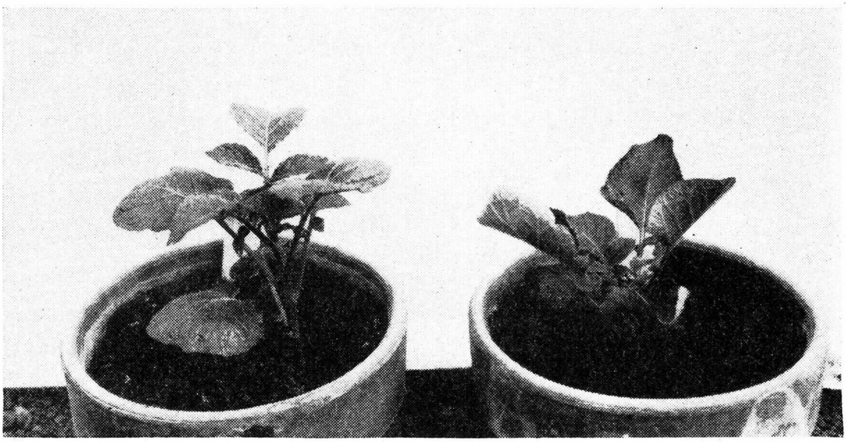

FIGURE 49.—Two index plants each growing from an eye of a tuber. The plant on the left is healthy; the one on the right shows leaf roll. The tuber from which this eye came will be discarded, whereas the potato tuber indexed as healthy will be retained and planted as a unit in a seed plot.

top removed. Several cans, each containing the sets from one tuber, are mounted on a special rack built to be set on the planting machine over the regular hopper. In planting, the operator picks up a can, pours the sets onto the revolving plate, and places one set in each of four consecutive openings (fig. 50). The empty can is returned to the rack, and the operation is repeated with another tuber. One extra space on the plate is left vacant between units to give proper separation of the units in the ground. Extra racks and cans are provided so that the only delay occasioned in reloading the machine is the time necessary to exchange racks. By operating with a slow, steady team, the planting can be done with few extra stops or delays. The following method has been used with some success by growers in Maine: The potato planter opens the row and at the same time places the fertilizer, and a wheel with knobs placed on the rim at regular intervals to mark the place for each seed piece is attached to the rear

of the planter. Men follow the machine and cut each tuber into four pieces, which are planted by hand in units of four. The planted rows are later covered by a horse hoe.

A special automatic machine has been developed by one manufacturing company that takes the selected whole tubers, cuts them into four pieces, and plants them in the row with suitable spacing between sets and extra spacing between units. This machine does not work well with long tubers; it operates best with the blocky, round ones. The Maine Agricultural Experiment Station made tests with long tubers for 2 years, but they were eventually discarded because occasionally the planter cut two tubers at once, did not cut seed pieces

FIGURE 50.—Planter converted to handle tuber units. The sets from each seed tuber are placed in a compartment of a tray. Several trays can be mounted on a special rack built on the planting machine over the regular hopper. In planting, the operator takes the seed pieces from one tuber and places one set in each of four consecutive openings. The operation is repeated with another tuber, and one extra space is left vacant between each unit so as to provide proper separation for the different units. (By courtesy of the Maine Agricultural Experiment Station.)

uniformly, and frequently carried small seed pieces into the following tuber unit.

Many growers believe that hand planting gives more uniform plants than any kind of machine planting, so that commercial plantings of tuber units of up to 150 acres have been made by hand.

Hill-Selection Method

The hill-selection method consists in marking the most promising healthy plants during the growing season and, at digging time, saving only the progeny from those showing the desired vigor and stem char-

acters thought to be correlated with productiveness, trueness to type, and uniformity in size of tubers.

Selecting only apparently healthy hills from a field where virus diseases are present may result in reducing these diseases to some extent the following year, but this method is entirely inadequate as an effective means of controlling potato virus diseases. In a test carried on in Oregon, one tuber from each hill selected as healthy was grown as an index in advance of field planting. It was found that 15 percent of the hills that looked healthy were definitely infected with rugose mosaic. These hill lots were discarded, but when the hills indexed as healthy were planted in the field it was found that 8.5 percent of the plants were still infected with rugose mosaic. This is explained by the fact that when a plant is infected late in the season no symptoms may be evident, but part of the tubers of such a plant may be diseased and the remainder healthy. For these reasons hill selection is not recommended as a satisfactory method for obtaining disease-free tubers although it is probably better than no selection at all.

Mass Roguing

In the mass roguing of seed plots the tubers are planted at random, either as whole or as cut seed. As soon as the plants are high enough so that the disease symptoms can be recognized, the diseased plants, including the seed pieces, are removed. These are placed as soon as pulled in a sack or other closed container to prevent the escape of disease-carrying insects and disposed of at a safe distance from the seed plot. Effective roguing by this method has proved to be very difficult. Experiments have shown that in the tuber-unit plot practically all the diseased plants are removed in the first roguing, whereas in the mass plot a considerable number of individual diseased plants are too small to show disease symptoms and cannot be removed before the second or third roguing. The mass-roguing method, therefore, is not recommended.

SEED PLOTS

It is recommended that growers of seed potatoes set aside a seed plot of about one-tenth the total acreage and separated from other potato plantings by at least 500 feet, in order to reduce the danger of insects carrying diseases from the general field to the seed plot. If possible, only tuber-indexed stock should be used, and this should be planted in tuber units. Any diseased units not eliminated by tuber indexing should be rogued and disposed of at a safe distance from the seed plot. In addition to this, some growers have found it advantageous to harvest the hills about 6 to 8 weeks before they are mature. Such procedure eliminates the movement of virus into the tubers from vines that become infected late during the current growing season. Experiments conducted in Maine during the summer of 1937, when aphids were abundant and leaf roll spread rapidly, showed that tubers harvested on August 10 developed only 1 percent leaf roll the following year, whereas tubers from the same plot harvested on September 26, when planted the next year, showed 25 percent leaf roll.

SEED DISINFECTION

When new land is being used or when old land is not heavily infested, it is advisable to treat seed potatoes before they are planted for the control of a number of skin diseases, such as scab and rhizoctonia canker. Disinfection may be regarded as a factor in raising better crops only insofar as it destroys parasites on the outside of the tubers. In the case of internal troubles other methods of control must be used. Ordinarily whole tubers are used, but in some cases it may be desirable to treat cut seed pieces. Although treatment of the latter has been done with satisfactory results in some localities, additional tests should be conducted before such treatment can be recommended for general use.

Several methods of treating potato tubers may be used. These include treatment with (1) mercuric chloride (corrosive sublimate), (2) acidulated mercuric chloride, (3) cold formaldehyde, (4) hot formaldehyde, and (5) yellow oxide of mercury.

Mercuric Chloride

The effectiveness of mercuric chloride, or corrosive sublimate, as a disinfectant for potatoes has been known for a long time. The original formula prescribes a solution of 1 part of mercuric chloride in 1,000 parts of water or 4 ounces in 30 gallons of water, in which potato tubers are treated for 30 minutes to 2 hours. *Mercuric chloride in full strength is very poisonous, but even the solution of 1 part to 1,000 parts is toxic. Where only a small quantity is to be used and the use is not continuous, only sufficient quantity for actual work to be done should be purchased, because of the danger of storing the surplus in broken packages.* Mercuric chloride goes into solution very slowly in cold water, and it should therefore be first dissolved in a small volume of hot water. The solution should be prepared and used in wooden, enamel, or concrete containers. The solution decreases in strength with use. To correct this, one-half ounce of the chemical should be added for every 4 bushels of potatoes treated for 2 hours. If a shorter treatment is used, the amount of chemical added should be reduced proportionately. If the potatoes are treated 1½ hours, add three-eighths ounce. Enough water should be added each time to bring the solution up to its original volume. Make up a fresh solution after four treatments. Wetting the potatoes for 20 to 24 hours before treatment helps to remove dirt, softens the sclerotia of *Rhizoc onia.* and makes the disinfection more effective.

Acidulated Mercuric Chloride

To shorten the soaking time to 5 minutes, the Minnesota Agricultural Experiment Station developed what is called the "acid mercury dip." It is prepared by adding enough hydrochloric acid to the 1–500 mercuric chloride solution to make a 1 percent solution. Tubers need to be soaked in this solution for only 5 minutes. Tests made in Oregon in 1932 and 1933 showed that this method was practically as effective as the long-soak mercuric-chloride treatment, but it caused injury to the eyes and skin of the potato tubers in a number of cases, especially when they were not dried immediately after

treatment. Because of the danger involved, this method cannot be recommended for general use until some consistent means of overcoming this danger is found.

Cold Formaldehyde

The results of different investigators have shown that cold formaldehyde is not effective in controlling rhizoctonia canker. This solution is prepared by adding 1 pint of formalin (40 percent commercial formaldehyde solution) to 30 gallons of water, and may be used for the control of scab by soaking the uncut tubers in the solution for 2 hours.

Hot Formaldehyde

This method is not quite as effective as mercuric chloride but may be used where the equipment is available. It is used widely in some places. Previous to being treated, it is desirable to keep the potatoes wet for 24 hours. The solution is made up by dissolving 2 pints of formalin in 30 gallons of water heated to a temperature of 124° to 126° F., and held within these limits by steam or by means of a fire maintained beneath the tank. They are then dipped for 4 minutes. A false bottom to the tank is necessary to keep the tubers at the bottom from becoming overheated. The solution should not be warmer than 126° F. because above this temperature injury to the sprouting of the potatoes results, nor should it be cooler than 124° as it would then not control the diseases if the tubers are dipped for only the 4-minute period. To allow for condensation water when live steam is used for heating, 0.9 pint of formalin should be added after every 50 bushels of tubers are treated. The solution does not lose its strength on standing if it is well covered. and may safely be kept thus for a few days or weeks.

Covering the tubers with a canvas or burlap for an hour after treatment adds to the efficiency of this method. *Formaldehyde solution, whether cold or hot, does not corrode metal and is not a dangerous poison, although it is poisonous if used at full strength.*

Yellow Oxide of Mercury

Yellow oxide of mercury was first used for treating potatoes at the New York State (Geneva) Agricultural Experiment Station in 1929. It has been tested every year since and found to be the best material for an instantaneous dip. It is as effective as mercuric chloride in the control of rhizoctonia canker. *Yellow oxide of mercury is very poisonous, and only sufficient quantity for actual work to be done should be purchased to avoid danger of storing surplus in broken packages.* The best results are obtained if the tubers are planted within a few days after they are treated. If the time interval between treatment and planting is greater than 10 days, it will result in retarded vine growth and reduced yields. It is recommended for treating whole tubers.

One pound of yellow oxide of mercury (technical grade) is added to 15 gallons of water in a wooden container or a metal container painted with a good coat of asphaltum paint. This mixture is stirred vigorously with a wooden paddle until all the oxide is in suspension. A basket of seed potatoes is then dipped into the liquid, plunged up

and down two or three times, and turned sidewise at the same time to insure complete wetting of the pieces and to keep the solution well stirred. The basket of treated potatoes is then removed and drained, and the tubers are dumped into a crate or open container where they will dry.

Additional mixture may be made up and added to the treating tub as needed. It is very essential that the mixture be thoroughly stirred before it is poured into the treating tub so that the yellow oxide, which is heavy, will not settle. The mixture does not lose strength and can be used as long as any is left. Fifteen gallons will usually treat 100 or more bushels of seed potatoes. The cost of the chemical is less than 2 cents for each bushel of potatoes treated.

For a time this treatment was very popular in New York State, and a few years ago the yellow oxide of mercury was used to treat approximately 100,000 bushels. Recently its use has declined somewhat due to the discovery that in some sections with nonacid soils any mercury material, either added on treated seed or mixed with the fertilizer, tends to increase scab.

This treatment, therefore, is not recommended in areas where the soil is alkaline enough to favor the development of potato scab.

SUBERIZATION

It is believed that one of the major causes of potato seed-piece rot is the improper healing of the cut surfaces. Omission of practices that would bring about healing is responsible for considerable seed-piece rot in the field, resulting at times in complete crop failures. The planted seed pieces that are not completely rotted before the eye has had an opportunity to send out a shoot may give rise to a weak or to an apparently normal plant. Later in the season, such plants may turn yellow and die prematurely. If the plants are still alive when dug, they will show the remnants of a rotted seed piece clinging to the underground stem, and the interior of the stem will be hollow and discolored. Tubers from such infected plants will give rise to healthy plants the following year, indicating that the trouble is not due to an organism carried over in the tuber.

This trouble may be avoided to a large extent by planting whole tubers or by providing conditions for the proper "corking over," or suberizing, of the cut seed pieces. Suberization is a very simple process and is based upon three essential conditions which are necessary to assure the formation of a layer of cork cells over the cut surfaces, namely, the presence of air (oxygen), proper humidity, and proper temperature (from 60° to 70° F.). If these three conditions are furnished, a protective layer of cork cells will develop over the exposed cut surface, forming an effective barrier against decay organisms that may be present in the soil after the seed pieces are planted. If any one of these three conditions is lacking cork cells will not develop, but the exposed cells will die. This may result in a shriveling of the seed piece, or the surface may dry hard and later crack. When such seed pieces are planted without a protective layer of cork cells, parasitic fungi and bacteria which are usually present in the soil may invade the seed piece and cause it to rot. Seed pieces may be planted immediately after being cut provided the soil is not

too wet or too dry and the weather not too cold. Under such favorable conditions the seed pieces will suberize in the soil before the soil organisms have had an opportunity to invade their tissues. When such conditions exist, special measures to bring about suberization before planting may not be necessary.

As the healing of cut seed pieces is so simple and inexpensive and the certainty of a perfect stand so well compensates for the little trouble involved, there is no valid reason why every grower should not suberize his seed prior to planting, especially in areas where seed-piece rot is a problem. The writer has never yet found any considerable seed-piece rot in fields where sound seed was properly healed over before planting.

It may be necessary to slightly modify the method of suberization in different localities because of the variation in the humidity of the air. The freshly cut seed pieces may be placed in ordinary burlap bags that previously have been moistened in water. Care should be taken not to use any bags that previously contained fertilizer or salt, as these chemicals may cause burning of the seed pieces. Ordinarily the humidity within the bags is high enough to insure proper suberization of the seed pieces if they are kept in a protected building or shed. If they are stored in a place where the bags dry out quickly, it may be necessary to sprinkle them occasionally, or to cover with a few additional moist bags. If the weather is cold it may be necessary to artificially heat the building. Suberization will take place most rapidly at a temperature of 60° to 70° F. The bags of potato pieces should not be stacked too high, as this may exclude air (oxygen), which is very necessary to complete the corking process. Storing the cut pieces under such ideal conditions will cause a protective layer of cork to be developed within 48 hours. Tests conducted in the United States and Canada have shown that when this method of healing is used, land plaster or sulfur application to the seed is not necessary. The use of these substances may be somewhat of an aid as a fungicide in preventing seed-piece rot if suberization is not practiced, but it is far less effective in eliminating seed-piece decay than is the suberizing method.

It should be remembered that the best results are always obtained by using sound tubers that have been kept under ideal storage conditions. Tubers that are beginning to shrivel and from which the sprouts have been removed at various times do not readily suberize.

SPRAYING

In order to control some of the leaf diseases of potato, such as late blight, spraying has to be practiced. For this purpose bordeaux mixture 5–5–50 has given the best results. Calcium arsenate or lead arsenate is added at the ratio of 2 pounds to 50 gallons of water when needed to control the Colorado potato beetle and flea beetles. The materials required for making 5–5–50 bordeaux mixture are copper sulfate 5 pounds, lump lime 5 pounds, or 7 pounds hydrated lime, and 50 gallons of water. A convenient method of making up this spray mixture is to dissolve 5 pounds of pulverized copper sulfate in 25 gallons of water either by suspending it in a sack near the top of the water over night, or in a small quantity of hot water; slake the 5 pounds of lump lime gradually in a small amount of water and

dilute the milk of lime to 25 gallons; or mix the 7 pounds of hydrated lime in 25 gallons of water; then pour the two solutions together in a third barrel and stir vigorously. The resulting mixture (bordeaux mixture) is of a milky-blue color. If it is impossible to spray at once, three-fourths ounce (a heaping tablespoonful) of sugar dissolved in a small amount of water should be added to each barrel of 50 gallons of spray mixture. This will keep the spray mixture in good condition for a long time; otherwise, the spray would be worthless after about 24 hours.

To be effective, spraying must sometimes be started when the plants are from 4 to 6 inches high and be continued at regular intervals throughout the growing season. During some years and in some localities 5 or 6 applications are sufficient; under other conditions from 10 to 12 applications are none too many. On the other hand, in some years spraying may not be necessary, or at least not until the disease appears. The State experiment station or the local extension service should be consulted as a guide to local practices, as the spray programs may vary in different parts of the same State.

It is a good practice to keep all new growth protected with the fungicide and to renew the application on the older growth. To give the vines a good protective coating, an application of from 60 to 75 gallons to the acre is required when the plants are small, and from 100 to 125 gallons when they are large.

Lime-sulfur sprays have given good results in controlling psyllids and flea beetles in some of the Western States, as discussed on page 45.

DUSTING

Many growers prefer to apply copper-lime dust rather than bordeaux mixture for the control of foliage diseases. One reason for this is that spraying is a rather inconvenient task to perform. Dusting is more easily done and requires less expensive and less complicated machinery. Much experimental work conducted in a number of States has demonstrated that dust properly applied will give almost as good late blight control as the spray. A very satisfactory dust for spraying potatoes is a mixture of monohydrated copper sulfate and hydrated lime with powdered lead arsenate or calcium arsenate added when an arsenical poison is necessary. The materials must be so fine that 95 percent of the mixture will pass through a 200-mesh sieve. The percentages of copper sulfate used vary somewhat, but 20 percent is considered a satisfactory amount. When an arsenical is needed, either lead arsenate from 7 to 15 percent, or calcium arsenate, from 10 to 25 percent, replaces an equal percentage of the lime. It is also possible to purchase the dust already mixed.

The amount of dust needed depends upon the size of the plants and the percentage of copper in the dust. The amount of copper used is approximately the same as that found in the amount of bordeaux mixture needed to give complete coverage. Generally, the same number of applications of dust as of spray will be needed during the season to give protection. When the copper-lime dust comes in contact with moisture on the leaf, the particles of copper sulfate and of lime combine to form a bordeaux mixture. If the

dust is applied when the leaves are dry, it is likely to be blown off. It is therefore desirable to apply the dust early in the morning when the leaves are covered with dew.

Dusting is often used on peat land, as it is frequently impossible to operate heavy sprayers on these soils. On hilly land, or where it is difficult to get water to operate sprayers, dusting is often preferable.

DEVELOPMENT OF DISEASE-RESISTANT VARIETIES

One of the most effective means of combating potato diseases is through the development of varieties that are resistant to one or more diseases. In recent years the production of resistant varieties has been given much consideration in the United States and elsewhere. This work has been emphasized especially in the national potato-breeding program, which is conducted cooperatively between State agricultural experiment stations and the United States Department of Agriculture. As a result of these efforts, five varieties, Katahdin, Chippewa, Houma, Sebago, and Earlaine, have been developed, which are resistant to the mild mosaic potato virus and which have been distributed to growers. A number of seedling varieties not yet ready for release are immune from the virus known as the latent mosaic of healthy potatoes or virus X.

One of the new varieties, Sebago, recently distributed to growers by the United States Department of Agriculture, is not only resistant to mild mosaic as indicated above but is also very resistant to late blight. Several seedling varieties have been produced that are highly resistant to common scab. These are being tested in a number of States to determine the growing conditions to which they are best adapted. It is possible that none of these excel the standard varieties in yield and quality, but genetic evidence indicates nothing to prevent the production of varieties with high yield and good cooking and market quality, combined with scab resistance. A number of established commercial varieties and some of the new seedlings have been found to be resistant to potato wart. The State experiment stations will be able to advise growers regarding the best adapted disease-resistant varieties as demonstrated by local tests.

STORAGE

The primary purpose of storage is to protect a more or less perishable fruit or vegetable product from freezing or injurious chilling and from overheating. To keep storage and transit diseases in check attention must be given to proper ventilation, humidity, and temperature. Stored potatoes need thorough circulation of air, and this should not be so dry as to cause an excessive shrinkage of tubers which weakens their vitality and resistance to decay. Poor aeration may cause blackheart. The best temperature for the storage of potatoes is between 36° and 40° F. Adequate ventilation and humidity and the right temperature are attained by proper construction and the management of storage houses, as described in Farmers' Bulletin 847, Potato Storage and Storage Houses.

SEED-POTATO CERTIFICATION

Seed-potato certification in the United States was begun in 1914. Its purpose was to provide the purchaser in the Southern or Western States with reliable seed true to name and free from disease and varietal mixture, and at the same time to encourage the building up of a specialized potato industry in the seed-growing States. Under the prevailing conditions at that time it was very difficult to induce the buyer of seed potatoes to offer any premium for a better product. When someone else offered him potatoes at lower cost, he would take them, disease or no disease, because he had no guarantee that any premium he might pay would assure improved quality. In the same way, it was difficult to get the growers in the North to make the necessary effort to improve their seed potatoes, as they were unable to obtain a premium as a reward for their extra care in producing a better grade of seed. A certification system serves a double purpose, because it guarantees to the buyer that he is purchasing a superior grade of seed and enables the seed-potato grower to get a higher price for his product than for table stock.

Since 1914 numerous improvements have been brought about in the rules and regulations governing this service. The quality of certified seed potatoes has improved considerably, owing to additional knowledge gained in methods of control of diseases such as tuber indexing and the use of tuber-unit plantings, and because of the more rigid standards that have been put into force.

In practically every State where seed potatoes are grown, a seed-certification agency exists. It may be the extension service, the board of agriculture, the horticultural inspector, or the State potato growers' association, depending upon the policy of the State concerned regarding the assignment of this type of work. The grower who desires to register his field for certification generally sends an application blank properly filled out to the certification agency or to the county agent of the county in which the field is located, usually several weeks prior to date of inspection. The regulations vary in different States, but ordinarily a certification board determines the eligibility of fields for inspection. The source of seed used is an important factor and is so considered in approving fields for certification. Growers whose applications for certification have been approved must pay a nominal fee to cover the cost of the inspection service. The number of inspections made in the field varies from two to four, and these are often supplemented by a bin inspection. If a field of potatoes fails to meet the certification requirements and is turned down at the first or second inspection, a fraction of the fee is refunded. In case the field meets all the requirements, sufficient tags are issued to be attached to the containers, sometimes with a lead and wire seal so as to necessitate the breaking of the seal in emptying the container. Any seed grower who is found guilty of misusing the certification tags or violates any of the rules and regulations for the certification of seed potatoes may have his certification revoked.

Although the quality of certified seed potatoes has considerably improved since this service was first introduced, there is still need for further improvement and for greater uniformity in the certifi-

cation regulations of the seed-producing States. It would be desirable to have a central agency, either the State department of agriculture, the State agricultural college, or the State potato growers' association, provide foundation stock. This material should originally be tuber indexed, and only the potatoes indexed as healthy should be planted in tuber units. During the growing season the plot should be thoroughly inspected and all diseased and weak plants promptly rogued out and carried from the field.

Any grower who desired to have his fields entered for certification should be required to start with foundation stock, which should be planted in tuber units to facilitate roguing and inspecting. A representative sample from any field that met certification requirements would have to be submitted and planted early the following year in one of the Southern States. In case the plants from such a lot should show more than a designated low percentage of disease, the grower would not be permitted to plant his own seed but would have to start again with new foundation stock before his fields would become eligible for certification.

This procedure or a slight modification of it is now used successfully by a few States, and the adoption of similar methods by other States will do much to improve the quality of certified seed potatoes.

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